BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits

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Authors	Olle Olsson (SEI), Marek Giełczewski (WULS), Jari Koskiaho (SYKE) & Karina Barquet (SEI)
Contributors	Thao Do (UU), Neil Powell (UU), Jennifer McConville (RISE), Marcus Carson (SEI)
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X	PU	Public.
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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, and the "experts" who define these measures have little engagement with industry, investors, civil society and authorities. This problem is exacerbated 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 many of the challenges in 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.

Focus will be 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 will be given to 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 RETURN is to improve the adaptation and adoption of eco-technologies in the BSR for maximum efficiency and increased co-benefits.

The **specific objectives** of the project can be divided into 6 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. RETURN will:

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

- Development of decision support systems for sustainable eco-technologies in the BSR.
- Contribute to better assessment of eco-technology efficiency via integrated and participatory modelling in three catchments areas in Finland, Sweden and Poland.
- Contribute to methodological innovation on application and adaptation of eco-technologies

2) Reduce knowledge gaps on policy performance, enabling/constraining factors, and costs and benefits of eco-technologies

- Assess the broader socio-cultural drivers linked to eco-technologies from a historical perspective
- Identify the main gaps in the policy environment constraining the implementation of emerging eco-technologies in the catchments around the Baltic Sea
- Inform 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) Provide a framework for improved systematic stakeholder involvement:

- Develop methods for improved stakeholder engagement in water management through participatory approaches in the case study areas in Sweden, Finland and Poland.
- Enact 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.
- Bring 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.
- Disseminate results and facilitate the exchange of learning experiences, first within the three catchment areas, and secondly across a larger network of municipalities in the BSR.
- Establish new cooperative networks at case study sites and empower existing regional networks by providing information, co-organize events and engage in dialogues.

4) Support commercialization of eco-technologies:

- Identify 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).
- Identify potential constraints and opportunities for integration and implementation of eco-technologies using economical models.
- Facilitate the transfer of eco-technologies contributing to win-win solutions to multiple and interlinked challenges in the BSR.
- Link 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 RETURN's envisaged outputs, existing networks, and established methodologies and services.

5) Establish a user-driven knowledge platform and improve technology-user interface

- Develop an open-access database that maps out existing research and implementation of eco-technologies in the BSR. This database will be intuitive, also 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
- Develop 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 media of knowledge.

1.2 Project Structure

BONUS RETURN is structured around 6 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.

1.3 Deliverable context and objective

The current deliverable (6.3) is part of WP (6). The objectives of WP (6) are to *enable a co-enquiry process between stakeholders and the project. At the regional level the 40 municipalities connected to the Race for the Baltic will act as a sounding board to provide input to the EBR in WP2. Stakeholder platforms will be established at the case study sites to support the identification of eco-technologies for analysis in WP3, WP4 and WP5. These platforms will serve as opportunities to further test, develop, adapt and use the eco-technologies based on the assumption that their effectiveness depends on context, as defined by institutional, economic, social and bio-physical barriers and opportunities. WP6 will thus contribute to understanding historical drivers, policy instruments and governance structures and local needs with regards to implementation of the selected eco-technologies in the three case study sites. WP6 will be responsible for developing and facilitating an innovative game system, using the empirical materials generated throughout the project to support the co-learning environment and more specifically mediating the interactions and critical reflection between the WPs and between the project and stakeholders*

The aim of this deliverable is to explore the role that societal values play, and have historically played, when it comes to acceptance of solutions for circular flows of nutrients and carbon. To investigate this issue, the practice of sewage sludge application on farmland is analyzed as case example to elicit improved understanding of the challenges involved in implementing circular solutions. The report provides a historical background on how application of sewage sludge on farmland has been governed and discussed in a broad context as well as in the three BONUS RETURN pilot basins.

1.4 Outline of the report

The report is structured as follows. Section 2 draws on available research literature to a) give a broad historical overview of the practice of circulation nutrients from human excreta and b) provide an overview of current practices and associated policy developments in the EU. Section 3 shifts focus to the three BONUS RETURN pilot basins and describes the history and current practices in each basin when it comes to sewage treatment in general and sewage sludge management in particular. The pilot basin description also includes examples of fertilizer products based on sewage sludge from waste water treatment plants in the respective basin. Section 4 concludes with a discussion that summarizes the different perspectives on sludge management to elicit some lessons about the prospects of producing fertilizer products from sewage sludge.

2 HISTORICAL REVIEW REPORT

2.1 Introduction

2.1.1 Socio-cultural aspects of eco-innovation success

There is no doubt that socio-cultural factors are highly important for determining whether an innovation will be successful or not. This is closely related to how *design* of technology reflects the socio-cultural preferences, economic and political resources of its makers and users (Bijker 1997). In other words, science and technology are inextricably linked to society, to the extent that the production of science and technology can be compared to the production of power in other spheres in which it both reflects as well as reproduces power relations (Latour 1999).

Nowhere is this clearer than in the marketing literature which has long highlighted the gains from consumer involvement in product design as way of increasing productivity (Lovelock & Young 1979) and in order to improve service delivery (Schneider & Bowen 1995) and service production processes (Lengnick-Hall 1996). More recently, this field has moved from viewing customers as passive “receivers” to treating customers as active co-producers. This shift has triggered a change in the fundamental question posed when addressing customers, from "What can we do for you?" to "What can you do with us?" (Wind 2000).

The latter question reflects a conceptual shift in how a product or service acquires value deriving from its *use*, rather than from *willingness to pay* (Vargo et al. 2008). The logic is that value is not simply added in a linear way, but mutually and interactively created (Ramírez 1999), and that a product or service incorporates value through its actual usage (value-in-use) rather than through its sale price (Vargo & Lusch, 2006). This co-creation of value involves a participatory process in which people and organizations together generate and develop meaning (Ind & Coates, 2013 in Alves), and end-beneficiaries determine the value of the product or service (Vargo & Lusch, 2008a).

For instance, the Apple iPhone, which by some measures is the most successful individual product of all time (Williams-Grut 2015), is arguably not vastly technically superior to other smartphones, yet elicits a premium price relative to its competitors. Many of the reasons for the iPhone’s success are connected to non-material values that go beyond the mere functions of the product itself. Although consumers tend to associate the iPhone and other Apple products with objectively important aspects such as product quality and intuitive design, the brand and the product largely draws appeal and consumer demand from its aura of creativity, “cool” and sense of community (Arruda-Filho et al. 2010). Beyond these perceptions of cutting edge design and technology, Apple's success is largely due to their adherence to co-creation principles, as they invite consumers as application creators and merchants and in so doing, generate loyal customers (Darmody 2009). More importantly, this co-creation process creates a natural platform for consumer-to-consumer interactions that create value not only through the sharing of technical advice, but also by sharing experiences and dreams about the brand (Moreno & Besson 2009).

Innovations and products used to mitigate environmental problems are in these aspects no different to innovations and products in general, although the importance of socio-cultural aspects may vary with the proximity to the end-consumer. One clear example that has received increasing attention in recent years is how the lack of adoption of clean cookstoves is largely related to how cookstove design may have focused too much on technical performance (e.g., combustion efficiency) than on actual user needs (Lambe et al. 2010). In the subset of innovations that concern water and sanitation, socio-cultural aspects are arguably particularly important to take into account, given that all things related to sanitation tend to be associated with a range of taboos, cultural norms and sensitive aspects in general (Garg et al. 2001).

2.1.2 Socio-cultural aspects of nutrient & carbon circularity

The objective of the BONUS RETURN project is to identify, analyze and support dissemination of innovations that can enable increased circulation of carbon and nutrients, with a particular focus on solutions that are applicable in the Baltic Sea region (BSR). A key component in the project is to draw on interactions with stakeholders in three case study basins in the BSR so as to identify determinants for success of different constellations of eco-technologies. The rationale for the inclusion of three different basins in three different countries (Vaantanjoki in Finland, Słupia in Poland and Fyrisån in Sweden) is partly based on the need to allow for analysis of differences in terms of hydrological patterns and other geophysical factors, but also to enable comparison of how different constellations of innovations perform in different economic, political and not least socio-cultural environments.

Although the starting point of the BONUS RETURN project is a broad perspective of eco-technologies pertaining to circular flows of nutrients and carbon, part of the project will be dedicated to evaluation and testing of a small set of specific innovations. From late 2017 to early 2018, the project hosted an innovation challenge aimed at identifying a handful of technologies that would be selected for further analysis and testing within the project. In early April 2018, the winners of the challenge were announced, and all three innovations[1] in one way or another address the challenge of circulating nutrients and organic material from wastewater.

Currently in the EU-28, the most common method for recycling nutrients from wastewater is to apply sewage sludge to farmland (Eurostat 2018). This has become a popular practice as it is a low-cost source for farmers of important nutrients (especially phosphorus) and organic material, and also is a fairly inexpensive method for waste water treatment plants (WWTPs) to dispose of large volumes of sewage sludge (European Commission 2002). However, the use of sewage sludge as fertilizer has also been heavily debated in Europe as well as globally. Interestingly, there are substantial differences between countries as to practices concerning management of sewage sludge, even among the member states of the European Union. This is despite the presence of an EU directive (86/278/EEC) aimed at providing a common legal framework for management of sewage sludge.

The aim of this report is to provide a historical background on how application of sewage sludge on farmland has been governed and discussed both in the EU context, national contexts and in the three BONUS RETURN pilot basins. The report is structured as follows. Section 2 draws on available research literature to a) give a broad historical overview of the practice of circulation nutrients from human excreta and b) provide an overview of current practices and associated policy developments in the EU. Section 3 shifts focus to the three BONUS RETURN pilot basins and describes the history and current practices in each basin when it comes to sewage treatment in general and sewage sludge management in particular. The pilot basin description also includes examples of fertilizer products based on sewage sludge from WWTPs in the respective basin. Section 4 concludes with a discussion that summarizes the different perspectives on sludge management to elicit some lessons about the prospects of producing fertilizer products from sewage sludge.

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[1] TerraNova (Germany), AquaCare (The Netherlands) and RAVITA (Finland), see more info here: https://www.bonusreturn.com/single-post/2018/04/05/Winners-in-BONUS-RETURN-innovation-challenge-selected .

2.2 Human excreta as fertilizer: history and current EU practices

2.2.1 The key challenge: taking the circular economy from buzzword to business

Recent years have seen an increased focus of EU environmental policy discussions towards an ambition to strive towards a more circular economy, in contrast to the patterns of consume-discard that currently dominate resource use in Europe (MacArthur et al. 2015). However, circularity is easy to draw on a whiteboard, but more difficult to implement in practice (Blomsma & Brennan 2017). When it comes to implementation of circular solutions, there are numerous serious challenges largely because the linear model of resource utilization is deeply engrained in so many parts of the 21st century economy. The challenges come in various forms (for an overview, see Korhonen et al. 2018). Some are clearly to be found in the policy realm, with a general pattern of tax structures that place heavy burdens on the cost of human labor but are quite lenient towards use of finite resources (MacArthur et al. 2015). Other challenges are more related to how individual behavior and socio-cultural patterns have been shaped by linear means of consumption. Here there are interesting discrepancies between the way consumers *perceive* the concept of circularity and how they *act* on it in their actual consumption patterns. For example, in a Dutch study of consumer attitudes towards buying used and refurbished smartphones, interview subjects were generally quite positive towards the concept as such but did not act accordingly. The reasons for this discrepancy are several, but are to a large extent related to perceptions of used products as inherently inferior and a much poorer buying experience, especially the “lack of the thrill of newness” (van Weelden et al. 2016).

2.2.2 Circulation of human excreta to farmlands: early history

Discussing circularity in connection to wastewater treatment adds another layer of complexity when it comes to socio-cultural aspects, namely that of attitudes towards human excreta. Throughout the history of civilization, people across the world have been conflicted by two distinctively different views on their own by-products: on the one hand, excreta are filthy and shameful and best kept out of sight and smell, on the other hand, they are highly valuable as fertilizer in agriculture (Rockefeller 1998; Richardson 2012).

Different cultures have leaned towards one of these two positions. Notably, East Asian civilizations have historically been generally positive towards agricultural application of “humanure” (Richardson 2012; Ferguson 2014). This has been highlighted as an important factor for the economic success of Indian, Chinese and Japanese civilizations relative to European in the centuries leading up to the 16th century. It has been estimated that even in the early 20th century, more than a third of the nitrogen applied as fertilizer to Japanese fields came from human excreta. In contrast, the European attitude at the time was rather characterized by ambivalence and leaning more towards “dispose” than “recycle”. However, 19th century Europeans who had visited Asia and learned about the agricultural use of ordure and urine lamented at the opportunities lost in the European practice of simply discarding “urban manure” (Ferguson 2014). The 1800s did also witness an increase in the practice of utilizing “nightsoil” as fertilizer in several countries in Western Europe, but this was marred by practical problems such as the fact that humans produce excreta all year round whereas farmers only need fertilizer at certain times. There was thus the need for some sort of storage solution, one of which was to mix the excreta with lime and peat to improve storage properties and overall logistics (Bernes & Lundgren 2009).

From the second half of the 1800s, however, water-based sanitation systems started to be introduced first in Great Britain and then, gradually and at different paces, in the rest of Europe. It has been argued that this created a disconnect between humans and human waste and packaged through a discourse of “flush and forget” (Richardson 2012). One consequence of this was that raw excreta volumes started to decrease as more and more outhouses were abandoned for flush toilets. Instead, new problems started to arise related to discharge of untreated sewage wastewater into waterways. There was a prevailing view that rivers and lakes were “natural septic tanks” that diluted the sewage water to harmlessness (Bernes & Lundgren 2009). The more immediate disturbing effects – in the form of foul smells etc. – were essentially solved by discharging the sewage waste water further and further away from densely populated areas (Swanson et al. 2004; Bernes & Lundgren 2009; Richardson 2012).

2.2.3 Sewage sludge management in the EU: current status

Our discussion hitherto has been on the application of "raw" human excreta to farmlands. In moving into the 20th century, there has been a gradual rise of urban sewage treatment based on water transport and centralized WWTPs. It is worth noting that the construction of WWTPs in Europe has not taken place in lockstep all over the continent. Rather, there are large differences between countries and within countries as to when various levels of wastewater treatment infrastructure were implemented. Regardless, our focus now shifts towards sewage sludge, a WWTP by-product which essentially did not exist before the wastewater treatment era (National Research Council 1996).

In a modern WWTP, incoming wastewater is treated in various physical, chemical and biological processes that collectively aim to produce water that is sufficiently clean to be released back into the environment. Sewage sludge refers to a solid or semi-solid by-product of these processes, high in organic matter and essentially composed of all that is removed as the waste water is cleaned (Rizzardini & Goi 2014). Sewage sludge volumes can quickly become quite substantial (especially in WWTPs in larger cities) and thus need to be managed.

In the EU, around 10 million tons (dry matter) of sewage sludge is generated every year. In terms of treatment, the first decades of sewage sludge treatment in Europe were dominated by two practices; landfill or (to use the same strategy as with the sewage waste water) dumping. The model was first to dump the sludge into an adjacent waterway, and as foul smells became unbearable, go further and further away to find more suitable locations offshore. In the 1960s, sludge from Stockholm was dumped both in the deeper parts of the Baltic Sea and as far away as the mid-Atlantic, off the Azores (Bernes & Lundgren 2009). Although ocean dumping of sewage sludge is still practiced in e.g. the Mediterranean (Kress et al. 2016), it has been banned in the EU since around the turn of the millennium (Christodoulou & Stamatelatou 2016). In terms of current practices of sludge treatment, exact numbers are difficult to produce as data quality is poor, both pertaining to total volumes and treatment methods used. However, recent estimates show application of sewage sludge on farmland to be the most common means of disposal. Almost half of sewage sludge volumes in the EU-27 is used for agricultural purposes, with incineration making up slightly less than 25%. Other methods such as composting or storage make up the remainder (Bianchini et al. 2016).

There are pros and cons to each of these different treatment technologies[2].

- **Landfilling** of sewage sludge is conceptually quite simple, but highly problematic for a host of reasons, including, but not limited to, shortage of storage space, risks of air pollution, risks of leakages and the fact that valuable resources are not re-used.
- **Incineration** can be done either in facilities that only process sewage sludge or co-combusted with other fuels. Incineration solves the disposal problem but as the organic material is combusted, the opportunities to use this as soil improvement are lost. It is quite possible to recycle phosphorus from the ashes, although if there is co-combustion, the complementary fuel has to be carefully selected (von Bahr et al. 2017). A barrier to this route is that the recovered phosphorus tends to be quite expensive compared to mineral phosphorus.
- **Composting** of sewage sludge is not really a disposal route as such but rather a means of pre-processing the sludge to the point where it can be used for other purposes such as aggregate

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[2] See e.g., Lehmphul (2015) or Rizzardini & Goi (2014) for more detailed descriptions.

in different construction projects or as a component in soil used for landscaping, golf courses and the like.

- Finally, **application of sewage sludge on farmland** has been a popular method primarily because it is a low-cost solution that both benefits farmers (who receive low-cost fertilizer and valuable organic material as soil improvement) and solves the disposal problem for WWTPs. However, as we will further explore in this report, this approach is increasingly being challenged for several reasons pertaining to possible hazardous contaminants in the sludge as well as general societal acceptance.

There are large differences among the EU member states as to the treatment methods preferred. **Figure 2** below shows the mix of utilization methods used in seven BSR countries in 2012.

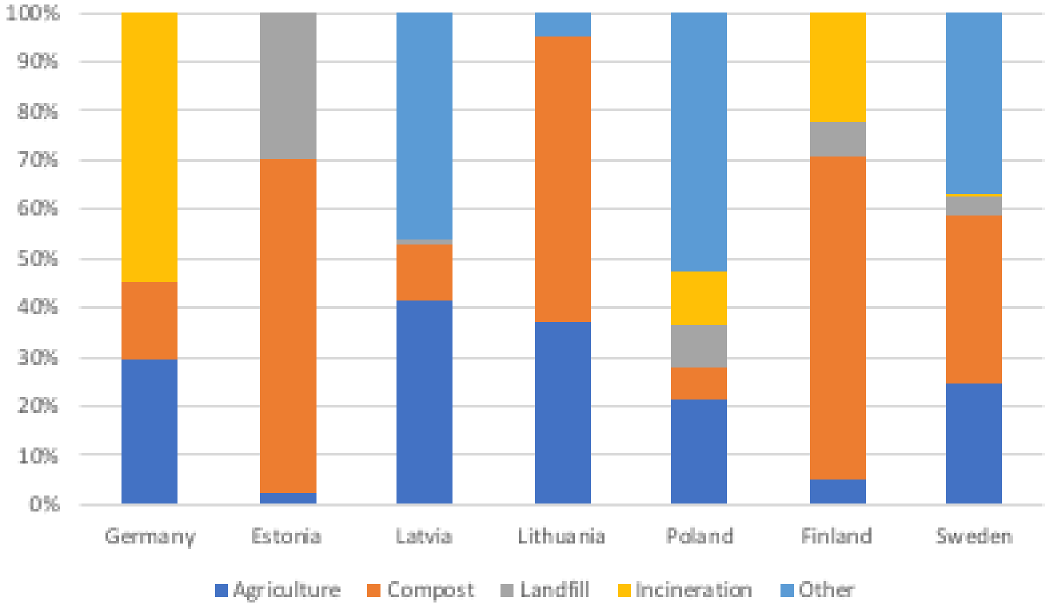

Figure 1. Sewage sludge treatment methods in seven Baltic Sea countries in 2012. (Data source: Eurostat)

As can be seen, there are substantial differences between the countries, with Germany dominated by incineration, Estonia, Lithuania and Finland by compost and Poland, Sweden and Latvia utilizing a mix of different methods[3].

One aspect that has been identified as a reason for this heterogeneity is the lack of a relevant EU policy framework on treatment of sewage sludge. The so-called "Sludge Directive" (86/278/EEC) is now more than 30 years old and has not been updated or revised despite several discussions and consultation processes (Inglezakis et al. 2014; Bergs 2018). Another limitation with the EU Sludge Directive is that it only includes limits on heavy metals in sewage sludge, whereas current debates are increasingly focused on pharmaceuticals and microplastics (Mininni et al. 2015; Bondarczuk et al. 2016). It should, however, be noted that treatment of sewage sludge has been affected by changes in adjacent EU policy processes, such as the 1999 Landfill Directive (1999/31/EC) that disincentivizes landfilling of organic waste in general.

In the absence of an effective common EU framework, regulatory differences between countries have emerged e.g., in terms of limitations on heavy metal content. Some countries such as the Netherlands have set very low limits on heavy metal content, which, essentially, makes incineration the only

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[3] Again, it is important to note that data quality is poor as the 2012 Eurostat dataset is among the more complete but still completely lacks information on the situation in e.g., Denmark.

possible option for sewage sludge management. The lack of a harmonized approach entails an obstacle to international knowledge sharing and technology exchange. The reasons for why different countries have chosen different routes are not clear (Rizzardini & Goi 2014) although Minnini et al (2015) hypothesize that international variation in agricultural use of sludge could be explained by population densities.

2.3 Perception, policy and politics in the sludge realm: the Swedish example

In this section, we provide a more in-depth review of the debate on application of sewage sludge on farmland in Sweden during the last four decades. While the topic has been discussed in other national contexts, most studies tend to focus on the debate in the U.S (Rampton 2003; Snyder 2005; Goodman & Goodman 2006). In terms of a European context, the Swedish case appears to be the most documented in the research literature (e.g., Hultman et al. 2000; Bengtsson & Tillman 2004; Öberg & Mason-Renton 2018). Sweden is also an interesting case because national policy has remained committed to farmland application of sewage sludge at a point in time when other countries in Europe have begun to abandon the practice (Kristola 2018).

Sewage waste management infrastructure based on centralized WWTPs began to be constructed in Swedish cities and towns in the decades following World War II. However, the process picked up pace only in the 1960s and it was not until the mid-1970s that all urban centers were connected to a WWTP (Bernes & Lundgren 2009).

The ambition to utilize the sewage sludge as fertilizer and soil improvement in agriculture was a part of the vision from the very start. It was a low-cost solution of disposal that also brought benefits to farmers. Some even referred to the sewage sludge as “Golden Filth” (“Smutsguldet”) (Augustinsson 2003; Bernes & Lundgren 2009). The practice was not free of controversy, as there was hesitance from both the public and some farmers about using human waste as fertilizer. Despite this, it was not until the 1970s that there were public guidelines regarding how to hygienise the sewage sludge to reduce the risks related to pathogens. The 1970s and early 1980s also saw an emerging intensive discussion about the possible risks related to other contaminants in the sludge, especially heavy metals and different forms of organic micropollutants (Hultman et al. 2000; Augustinsson 2003). This also led to increased focus on the need to reduce emissions of heavy metals into waste water systems and to generally reduce the use of heavy metals in society (Kristola 2018).

In the late 1980s, after a Greenpeace action in Gothenburg directed at highlighting the risks of different contaminants in the sludge, the Swedish Farmers’ Association (LRF) recommended their members not to apply sludge to fields. After the introduction by the Swedish Environmental Protection Agency (EPA) of new limitations on heavy metal content in the early 1990s and in connection with Sweden’s entry into the EU in 1994, the EPA concluded that there was no significant environmental risk connected with using sewage sludge on farmlands. A voluntary agreement on sewage sludge was then signed by the Swedish Water Association, LRF and the EPA that set out a framework for how to deal with the sludge issue (Augustinsson 2003).

However, this only worked for a few years. In 1999, there were reports of traces of flame retardants in sewage sludge which led the LRF to immediately go back to the recommendation of not using sludge on their farms (Hultman et al. 2000). After some further negotiations, the LRF announced that it would leave the decisions on the use of sewage sludge up to individual farmers. However, it was concluded that this was not a long-term solution and several different initiatives were launched to find something more permanent. This led to the development of a joint certification program called Revaq, which would develop limits on contaminants (in incoming wastewater). WWTPs that could reach the levels would then be eligible to use the corresponding sludge on farms. Revaq was launched in 2008 and currently about half of all Swedish sludge is certified.

Although the ambition behind Revaq was to establish a longer-term plan for dealing with sewage sludge, it has still not resolved the issue. Several Swedish grain mills will not accept grains that have been fertilized with sewage sludge (even if it is Revaq-certified), for fear of consumer backlash (Krantz 2012; Swedish Flour Milling Association 2018). Furthermore, since the launch of Revaq, concerns have been growing about contaminants that have previously not been in focus, particularly pharmaceuticals and microplastics. The consequence is that, despite that the "upstream work" has been highly effective (notably in terms of reducing heavy metal contents in the sludge), the future of sewage sludge application on farmland is looking bleaker (Kristola 2018).

It is worth noting that in 2001, it was decided that landfilling of organic material would be banned in Sweden from 2005. This includes raw sewage sludge, although landfilling of sewage sludge is allowed if it has been processed through composting (Henriksson et al. 2012). Regardless, this in effect removed one of the other alternatives that had thereto been used in Sweden and created a rather urgent need to expand other options. As the controversies regarding agricultural application seem to continue, this route is beginning to look less attractive, there is a general sense of urgency in Sweden to find new methods of dealing with sewage sludge in a way that also enables utilization of its phosphorus (Kristola 2018).

2.4 Sewage sludge treatment in Fyris, Słupia and Vantaanjoki basins

As noted in section 2, there are large differences between EU countries as to how sewage sludge is managed, as well as large differences between the subset of EU member states located around the Baltic Sea. The objective of the BONUS RETURN project is to support dissemination of technologies and solutions that can facilitate capture and re-use of carbon and nutrients in the BSR. A key component in this venture is to identify and analyze national and regional characteristics to understand the role that these factors may play as enablers or obstacles to implementation of eco-technologies.

In order to shed some light on the kind of issues that are relevant for this purpose, this section gives a historical overview of sewage sludge treatment in the three basins, with particular emphasis on the application of sewage sludge on farmland. Focus will be partly on actual patterns in terms of policies and management practice, but also on the political, institutional and socio-cultural aspects that have shaped policies and practices.

2.4.1 Fyrisån, Sweden

The Fyris river basin (1 982 km2) is located in the south-eastern part of Sweden. The Fyris River (Fyrisån) is a tributary of Lake Mälaren, which has its outlet through Stockholm into the Baltic Sea. The catchment area is distributed among forests (60%), agriculture (32%), wetlands (4%), lakes (2%) and urban areas (2%). The urban area is dominated by the city of Uppsala (population approx. 200 000) whose wastewater treatment plant discharges purified wastewater into the river. The Fyris River basin covers a quite diverse set of landscapes, including actively managed forests, agricultural lands in Sweden's 4th largest city, Uppsala. The water quality status of the river has also been very well documented for a long time, making it possible to e.g. trace effects of historical implementations of eco-technologies in WWTPs in the basin.

The Uppsala Waste Water Treatment Plant, "Kungsängsverket" was constructed in 1945 and Uppsala was thus one of the first towns in Sweden to be equipped with a WWTP. From the very beginning, the first step for treatment of the sewage sludge was anaerobic digestion, whereby volumes were reduced significantly and which produced gas that was combusted to produce process and space heating for internal use. After the anaerobic digestion process, the sludge was dried, after which it was retrieved by local farmers who used the sludge as fertilizer. Over time this practice was changed so that the

WWTP took over the responsibility for transportation and application of the sludge to designated farmlands (Flygt 1996, p. 157, 163).

The time period 1950-1975 witnessed an almost doubling of Uppsala's population which led to a commensurate growth in production of sewage sludge, which meant that larger areas had to be used for drying of the sludge. In order to address growing concerns about nutrient emissions to Fyrisån, new process steps were also added to the WWTP. This made the sludge treatment more complicated, and in turn demanded the introduction of an additional dewatering process before the open air drying (Flygt 1996, p. 164).

High water content continued to pose a problem to the economics of using the sewage sludge on farmland, as transportation costs could become excessive. Further investigations were made in attempt to find a process to drastically reduce the water content. As there was an excess supply of biogas produced from the anaerobic digestion process, it was in the late 1970s that the gas started to be used as fuel for drying the sludge. The drying process also acted as a form of hygienization and the result was a dried and pelletized fertilizer product called "Stallängskorn" (Flygt 1996, p. 165), see Text Box 1.

Text Box 1: Sludge fertilizer product example: Stallängskorn

Today all sludge used for fertilizer in the Fyris basin is sold on contract to commercial farmers only. However, there were attempts in the late 1970s and early 1980s at marketing of sludge-based fertilizer as a garden fertilizer under the brand "Stallängskorn" and looked very much like synthetic commercial fertilizer. After some time, a controversy ensued as the Uppsala municipality health inspector raised a public complaint about several inappropriate aspects of how this was marketed. Firstly, the packaging for Stallängskorn did not specify that the product consisted of sewage sludge. Secondly, despite the hygienization process, the product was not suitable for use as fertilizer for vegetables, because of concerns about effects from cadmium contents in the sewage waste, and this was not made clear on the packaging either. Thirdly, the health inspector was critical of how e.g. nitrogen content was stated not as "38 g/kg" but as "38 000 mg/kg", allegedly in an attempt to give the impression of a more powerful and effective product. Finally, the 20 kg bags in which the Stallängskorn was sold was decorated with a large picture of a Kungsängslilja (*Fritillaria meleagris),* the official flower of Uppsala, which was criticized by the health inspector as a dishonest form of marketing, unworthy of a municipally-owned company (UNT 1978). Although it is not clear to which extent this controversy was an additional factor, strong competition from alternative fertilizers caused slow demand and after failed attempts at exports to Finland and Egypt, production was shut down after only a few years (Flygt 1996, p. 165).

Throughout the 1980s and 1990s, sludge processing was developed in several ways. Equipment was upgraded and installed to enable biogas from the sludge to be used as fuel for city buses in Uppsala. However, the use of sewage sludge on farmland continued throughout the 1980s until the new Swedish EPA imposed new limitations in terms of copper content in sewage sludge used on farmland (Laurell 1988). The high mineral content in the drinking water system in Uppsala meant that copper from old pipes dissolved and ended up in the sewage sludge which in turn made it ineligible for use on farmland according to the new limitations. Consequently, the sewage sludge was instead landfilled or used to cover old landfills in the 1990s and early 2000s. In 2007, however, a new facility for treatment of drinking water in Uppsala was installed. The result was a more than 50% reduction of copper levels in the tap water in Uppsala, with a spillover effect that copper levels in the sewage sludge were expected to decrease as well. This made it possible for the Uppsala WWTP to be REVAQ-certified in 2013 (Uppsala Vatten 2012) which made it possible to resume application on farmland. Currently, the sludge in Uppsala is categorized into three different classes depending on quality, with the best quality sludge used on farmland, mid-quality sludge used for landfill cover and the worst quality sludge is incinerated. In terms of volumes, farmland application makes up the biggest share. It is worth noting that the landfill cover path will only be available for a couple of years more as most landfills will soon be fully sealed (Bergendorff 2014).

2.4.2 Słupia, Poland

The Słupia river basin (1 623 km2) is a diverse coastal catchment with an expansive area of dunes stretching along the coast. Agricultural land and forest represent 54 % and 42 % of the basin respectively. Urban areas constitute around 3 %, of which the largest portion is taken by the city of Słupsk with 95,000 inhabitants, and two smaller towns (Bytów and Ustka). All of them have their own wastewater treatment plants discharging purified wastewaters into the Słupia river system. The Słupia catchment is one of the largest catchments on the Polish coast that includes a large city (Słupsk) and thus it offers a unique opportunity to study both the pressure from rural and urban areas on water quality, which is predominant in this part of the BSR.

General information
The current Waste Water Treatment Plant in Słupsk was opened in 1986, after a 16-year construction process. It is operated by Wodociągi Słupsk SA (Słupsk Waterworks public limited company), which is responsible not only for waste water treatment, but also for drinking water production and supply, as well as management of the sewage system. Its operating area covers the City of Słupsk and two neighbouring rural communities – Gminy, Słupsk and Kobylnica.

At several stages throughout the waste water treatment process, solid wastes are generated, with the largest part being stabilized sewage sludge. Dealing with this is a major problem not only for the WWTP Słupsk but for all administrators of WWTPs in the country. On the one hand, it is large and valuable source of substrates (e.g., nitrogen and phosphorous) for fertilizer production; on the other hand, it is a potential source of harmful hazards such as heavy metal and/or pathogens.

Current sewage sludge treatment technological process
When rebuilding the WWTP in Słupsk, the plant was equipped with anaerobic digesters (currently three are working, with a fourth under construction) to reduce the waste volume and stabilize the sludge in order to make it safe for further processing. Additionally, the waste leaving the anaerobic digesters is dewatered in decanter centrifuges. Sewage sludge in this state can undergo different further processing such as combustion or composting. Initially, (1986 – late 1990s), sewage sludge was treated through anaerobic digestion and stored in heaps. However, already in early days, the Board of Słupsk Waterworks was looking for more useful ways of managing sewage sludge. Therefore, when planning the plant modernization, the plant was also equipped with a composting installation, with the vision to use it as base for fertilizer production.

The composting installation was prepared for utilization of biodegradable wastes - stabilized sewage sludge but also green wastes (plant biomass) - and opened officially in 1996, when the first trials of composting took place. In the time period 1998-2000, the composting process was operated in a so-called semi-technical scale to ensure proper functioning of the installation and it reached its full production capacity at the end of 2000. Currently, the installation is prepared to process biologically ca. 20 000 t/y of waste, including 13 000 t/y of stabilized sewage sludge. The remaining waste is acquired from other waste producers and consists of materials that are structurally necessary for proper technological functioning of the installation, such as straw, woodchips, branches and bark. After reaching the full production capacity, the installation was enhanced and modernized, including full roofing, modernization of the compost board and installment of deodorizing systems. The latter was very important in terms of attaining to the concerns of the local community. The composting installation is certified by the Marshall of the Pomeranian Region as compliant with R3 recycling process (recycling of organic substances, excluding solvents, by composting and other biological processes) set up by the Act on Wastes (Journal of Laws, 2018) and has also a status of Regional Installation for Processing of Municipal Waste.

After the sludge has been mixed with different forms of green wastes (including willow from the WWTPs own plantation, the actual composting takes about 9-10 weeks and is carried out according to clearly defined process. Throughout the process, there is continuous sampling and testing so as to monitor physio-chemical parameters and if there is any pathogen pollution. Once the compost pile has matured, it is sieved and moved to a separate storage area for distribution as an organic fertilizer called "BIOTOP", see Text Box 2. The composting rate is approximately 35%, (i.e., out of 20 000 tons of wastes produces about 7 000 tons of fertilizer).

It is important to note that the case of the WWTP Słupsk and its "BIOTOP" is rather exceptional in Poland for a waste water treatment plant of that size. Historically, landfilling has been the most common practice for sewage sludge management in Poland (above 40% in year 2000). However, in their analysis of future trends in sewage sludge management in Poland, Bien et al. (2011) indicated an on-going transition (starting in the early 2000s) to other solutions, mainly agriculture use and thermal processing (incineration). According to the *National Waste Management Plan 2014* (NWMP, 2010), incineration shall in 2018 account for 60% of total sewage sludge management, and be realized predominantly by large WWTPs (over 100 000 p.e. - person equivalent). The reasons for the focus on incineration is that there is an expected increase in the volumes of municipal sewage requiring treatment and it will be difficult to ensure a sufficient quality of sewage sludge at this scale. This is mainly due to high level of heavy metals (Bien et al., 2011). In this context, WWTP Słupsk is an example of an alternative way of managing sewage sludge by large WWTPs.

Text Box 2: Sludge fertilizer product example: BIOTOP

The final product of the composting process at Słupsk WWTP is an organic fertilizer called "BIOTOP". It has proven to be successful both technologically and commercially, and almost 90% of sewage sludge produced by the WWTP Słupsk is turned into the fertilizer. It fulfills legal requirements (sufficient level of desirable substances, mainly nutrients, and low level of hazardous substances, mainly heavy metals), and is well received and highly demanded on the market, with the whole production sold out already for months ahead. The product is attested and authorized for retail by Ministry of Agriculture. Composting process causes extensive hygienisation of the sewage sludge. Also, before the final distribution, the fertilizer is checked for quality in the Słupsk Waterworks laboratory. Additionally, linking anaerobic and aerobic processes in composting technology results in low GHG emissions and significant reduction of organic, harmful compounds. Therefore, the properties of the BIOTOP are satisfactory both in terms of level of useful substances (on average 2,5% nitrogen, 1,0% phosphorous, and 0,2% potassium), and low level of heavy metals well below official norms for composting fertilizer. Parasites (*Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.*) or *Salmonella sp.* bacteria are not present in the fertilizer. Predominantly, the sludge is used for improving physical, biological and chemical soil properties in primary agricultural production. However, it might also be applied for improvement of urban green areas, lawns, sport fields and golf courses, in forestry, floriculture, or in remediation of degraded areas. BIOTOP has proven to be particularly effective with good demonstrated uptake by plants and consequently, limited leaching to ground water. All this makes the BIOTOP an attractive product, which is in high demand, with reservations up to a few months ahead, mainly done by large farms (75% of production).

Production of the certified fertilizer from sewage sludge dates back to the beginning of the 2000s but was mainly undertaken by medium size WWTPs, due to a laborious certification procedure (Grobelak et al., 2016). Only in the last years have some of the large WWTPs started production of certified fertilizers. However, despite a few successful cases, several WWTPs have failed to carried out a certification procedure or have not reached good enough quality. An additional obstacle to the composting/fertilizer route is related to technological requirement for certain additions to the composting process (e.g. straw, bark, branches). The availability of these vary seasonally, a factor that has been hampering a development of this sewage sludge management (Grobelak et al., 2016).

A key driver of further developments in sludge treatment is that landfilling is banned by legal regulations introduced in 2016. Therefore, alternative ways must be used to larger extent. As noted above, incineration is the one promoted the most, but in 2016, only 20% of produced sewage sludge was incinerated (NWMP, 2016), still much below predicted share. This situation creates opportunities for increased use of sewage sludge for fertilizer production, especially so because – in contrast to Sweden and Finland – the practise is not strongly contested by farmers or other parties. If the product (fertilizer) quality is stable and fulfills the strict legal requirements on heavy metals content, it is in high demand by farmers as an economically profitable alternative to mineral fertilizers.

2.4.3 Vantaanjoki, Finland

The Vantaanjoki river basin (1 680 km2) flows through the Helsinki metropolitan area (ca. 1 million inhabitants) before discharging into the Baltic Sea. Purified sewage waters from this region are discharged into the open sea area in the Gulf of Finland. However, in the upper reaches of the river there are two towns (Riihimäki and Hyvinkää) with their own wastewater treatment plants that also discharge purified wastewaters into the river. The Vantaanjoki river basin is characterised by a variety of water resources problems, of which the most serious are the non-point source pollution from agricultural fields and the point source pollution coupled with stormwater runoff from the urban areas.

The amount of wastewater in the Helsinki metropolitan area began to increase already in the second half of the 1870s when the waterworks started to operate and the municipal sewage network was built. At that time, cleaning of waste water was discussed, but this was considered unnecessary. Water-based sanitation systems were however widely used in the beginning of the 20th century, which deteriorated the shoreline around the headland of Helsinki, as most of the wastewater was conveyed directly by the sewage pipes to the nearest shore. Eventually, the algae blooms that occupied the Töölönlahti Bay, coupled with local complaints and the concerning research results on the state of seawater, provoked the city’s health committee to find more suitable cleaning methods.

Thus, the first two wastewater treatment plants in Finland were built in Helsinki in 1910, based on septic tanks. The treatment plants brought some relief to the worst parts of Töölönlahti Bay, but contamination continued to grow in other shores. Different solutions were proposed for the situation, but the discussion lasted nearly two decades before more treatment plants were built. In the 1930s, activated sludge technology was put into operation in the newest plants, with the sludge used for agricultural purposes (Nissinen 2002). The construction program for sewage treatment plants was interrupted due to the World War II and the subsequent time of destitution, which continued until the 1950s. During the next two decades in 1960s and 1970s, wastewater treatment plants were built in different parts of the city.

Even though wastewater treatment capacity grew rapidly in the 1960s and 1970s, population increased even more rapidly. The cleaning effect was also influenced by the city's sewage system where the separated system was operational only in the new suburbs. The old sewerage network in the old city center, on the other hand, was a mixed system where rainwater and sewage water flowed in the same sewers which, in terms of treatment performance, is far from optimal. Thus, pollution increased in spite of the new treatment plants. In order to increase the effectiveness of the treatment, a wastewater committee set up by the city proposed the removal of eutrophication-accelerating nutrients from the wastewater in addition to the organic matter and pathogens. Phosphorous removal by the chemical parallel precipitation method was first experimented in the mid-1970s, and later this method was introduced more widely. Nitrogen removal was only experimented in the early 1990s, but with the tightening of EU directives, methods were extended from the test line to full operation at the Viikinmäki WWTP, which was established in 1994. In the mid-1980s, there were five wastewater treatment plants operating in Helsinki and the system had been found to be inadequate to prevent pollution along the coastal areas. Hence, Helsinki waterworks began to plan to replace these with a large, efficient central WWTP, of which the construction was completed in 1994 in Viikinmäki. The old plants were run down, but their equipment continued to operate in the opposite shore of the Gulf of Finland in Estonia and Russia.

The proposal of the Wastewater Committee to build a pipeline into the open sea was not carried out until the 1980s when another large-scale project, i.e. the Päijänne tunnel, for the water supply was completed. Cooperation between the municipalities, however, had started already in the 1960s, and the tunnel and pipeline projects thus included also Vantaa and three municipalities of Central Uusimaa region (Kerava, Tuusula and Järvenpää) located in the Vantaanjoki catchment. As for the remaining three major municipalities of the Vantaanjoki catchment, in Hyvinkää wastewater treatment is centralized at the Kalteva central WWTP, the first phase of which was completed in 1984 and the second phase in 1991. Previously, the treatment of the sewage waters from Hyvinkää was done in four minor treatment plants. The wastewater treatment plant of the Riihimäki municipality was built in the 1960s and it has been renovated and extended several times over the decades. The latest renovation was completed in 2014. In the Nurmijärvi municipality, there are two wastewater treatment plants; the larger Klaukkala plant and a minor one serving the Nurmijärvi central village. The treated sludge from these four wastewater treatment plants is utilized both as energy (biogas) and as fertilizer and in landscaping.

In Helsinki, the sludge from the wastewater purification process was at first used as fertilizer in agriculture. In the second half of the 1980s, however, the fertilizer use was hampered by suspicions of excessive heavy metal concentrations and radioactivity. This was at the same time that the standards for fertilizer use were planned to be tightened, so the Helsinki waterworks decided to compost all sewage sludge to fit for landscaping (see Text Box 3). The methane formed in the process is recovered and used as carbon neutral (fossil-free) electricity and heat for internal use.

Text Box 3: Sludge fertilizer product example: Metsäpirtin multa

Metsäpirtin multa ("Metsätpirtti topsoil") is a sludge-based fertilizer produced and marketed by the Helsinki Region Environmental Services Authority (HSY). It has been produced and sold since 1994, when the Metsäpirtti compost facility was first inaugurated. The fertilizer is produced by mixing sewage sludge from the Viikinmäki WWTP with peat and comes in two varieties: *Nurmikkomulta* for use on lawns and *Puutarhamulta* for use in gardens (approved by the Finnish Food Safety Authority for use on vegetables). This mixture is then put into a mechanically aerated composting process until the compost is deemed matured and stabilized. The next step is to add sand and a calcium-rich biotite powder (for *Nurmikkomulta)* or dry horse manure (for *Puutarhamulta)* after which the *multa* is ready for delivery to households in bulk (HSY 2018).

In terms of the debate on sludge treatment in general, the situation in Finland appears to have much in common with the Swedish development discussed in section 3. As noted above, the 1980s saw opposition from farmers' organizations towards the use of sludge as fertilizer. In the early 1990s, an outright ban was introduced by the Finnish Union of Agricultural Producers (MTK). The opposition among farmers was based on concerns about the impact that consumer perceptions of pathogens and heavy metals in the sludge would have upon Finnish agriculture. New legislation with strict levels of heavy metal content in the sludge introduced in the mid-90s did not suffice to fully alleviate farmers' concerns. In the early 2000s farmers' organizations once again stated their concerns towards the use of sludge. Interestingly, however, consumer organizations seemed not to have been very concerned about potential risks deriving from the use of sewage sludge as fertilizer. Despite significantly reduced shares of heavy metal pollutants in Finnish sewage sludge from the 1980s to the 2000s, in the last decades there has been a dominance of other sludge treatment methods, especially composting for use in landscaping projects (European Commission 2002).

2.5 Discussion

2.5.1 The technical challenges of recycling nutrients and carbon from sewage sludge

The circular economy has been much touted as a key framework for the transition to more sustainable societies. However, if the circular economy is to go beyond being a buzzword and manifest itself as change on the ground, key challenges have to be addressed. It is important to note that human societies have not drifted towards the linear “use-discard” model out of intentional malice. Rather, finding the root cause of the ubiquity of linear resource use requires us to acknowledge that there are some fundamental phenomena that steer towards linearity.

First, circulating valuable substances from wastes is at its very heart a problem of physics and functions of societal metabolism. Human societies extract resources from the natural environment and refine these to obtain materials and substances with particular properties which are then combined into different forms of technical artefacts, food products, textiles, chemicals and so on. As all these forms of products – often composed of a wide range of different materials and substances – are discarded, they are typically further mixed among themselves in various disposal schemes, be it sewage treatment processes or municipal solid waste management systems. However, as we have come to realize that this resource use pattern is simply not sustainable and we want to recover resources from things hitherto discarded, we face a challenge: all this blending and mixing makes it quite difficult to extract desired substances. The challenge is particularly steep given the lock-in that comes from decades of substantial capital investments in fixed infrastructures that often turn out to be unsuitable for circular solutions.

In sewage treatment systems, this manifests in the fact that the resources we want to extract from the sewage sludge and apply to farmlands – mainly phosphorus, nitrogen and organic matter – are intermingled with plenty of other substances that have accumulated along the way to the waste water treatment plant. At the very beginning of the chain, humans themselves contribute to this as their consumption of pharmaceuticals leads to these ending up in the sewage system, in addition to any other chemicals that are washed away in kitchen sinks or flushed away in toilets. Then, as excreta are transported to the sewage treatment plant, they are mixed with e.g., runoff from city streets and effluents from industrial processes. At the waste water treatment plant, all these flows are blended together for treatment. As waste water treatment systems become more and more sophisticated, they become more and more capable of removing unwanted substances before water is released back into the natural environment. However, the flipside of this is that whatever is removed from the wastewater ends up in the sludge.

In order to use sludge as fertilizer, it is crucial then to find a way to reduce the amounts of contaminants mixed in with the nutrients and organic matter. Broadly speaking, two pathways can be identified to do this. The *first* is to stop contaminants from entering the system altogether via upstream work, an approach that has been highly effective when it comes to reducing heavy metal contents in the sludge. The *second* is to implement an end-of-pipe process that purifies the sludge so as to remove the contaminants while simultaneously extracting nutrients and carbon for use as fertilizer and soil improvement. An obstacle to both of these approaches is the question of when the sludge is “clean enough”. As shown in the review of the Swedish debate, new problems with the sewage sludge seem to emerge just as the previous one has been addressed. By the 1970s, when hygienization processes had been implemented to address the problem of pathogens, the high heavy metal contents in the sludge started to become a cause of concern. Then by the late 1990s as ambitious upstream work had led to drastically reduced heavy metal levels, flame retardants (PFAS) surfaced as a risk factor, followed by pharmaceuticals and microplastics in the first decades of the 2000s[4].

2.5.2 Socio-cultural challenges of recycling nutrients and carbon from sewage sludge

Even though the “new” potential risks pertaining to sewage sludge can probably at least partly be mitigated by ambitious upstream work - such as regulations on the use of microplastics – it is important to note that mitigation of a quantifiable risk does not automatically entail mitigation of the *perception* of risk. As we noted in section 1.1, perceptions and emotions are critical when it comes to adoption and acceptance of innovations, and the fact that sludge recycling has repeatedly been deemed safe by authorities only for a new risk factor to be identified, may contribute to a general perception among the public that sludge is inherently risky. At the very least, a suspicion among the food industry that consumers could view sludge as loaded with negative connotations seems to suffice to make flour mills adverse to accepting grains that have been fertilized with sludge.

Having said this, it is interesting to note that the “public” may not be as concerned with risks from sewage sludge as the food industry seems to think. According to a report published by the European Commission (2002), Finnish consumers were said to be “indifferent” to the issue. Now, this may have changed in the past decade. However, the fact that a sludge-based fertilizer is bought by private households in the Helsinki region is an indication that the fear of consumer backlash against sludge-fertilized foods may be somewhat overexaggerated.

It is important to note that just like there are differences between the ways countries manage sewage sludge, there may also be differences between countries regarding *attitudes* towards sewage sludge, which in turn affects and is affected by the prevalent sludge management practices. Interestingly, in both Helsinki and Słupsk, sludge-based fertilizers are branded and sold as consumer products whereas in Uppsala, the sludge is only sold directly to selected farmers. The reasons for this discrepancy are not readily identified. It is possible that the failed attempts in Uppsala in the beginning of the 1980s (the “Stallängskorn” case) has permanently deterred from further attempts. Alternatively, it might just be that the current system of working with a smaller number of farmers is more suitable to its organizational structure. Further research is needed on this matter as well more generally on investigations into reasons for the differences between attitudes and management systems in different countries.

2.5.3 The next step: what is a “safe” way of circulating nutrients from sewage sludge?

The issue of potential or perceived risks of sewage sludge application on farmland is of crucial importance to its future. However, an additional factor concerns what we reviewed in section 2.2, namely the ambivalent and strained attitudes among societies when it comes to using human excreta to grow food. Finding a way to reconcile *a)* the drive to circulate carbon and nutrients from wastewater and *b)* the risks (real or perceived) and socio-cultural tensions associated with the use of human excreta as fertilizer, are two central dimensions for the implementation and scaling of circular innovations for sewage treatment. Here, it is important to acknowledge the fact that socio-cultural acceptance for a specific solution might need to be more prioritized than striving towards full circulation of nutrients and carbon. An example here is solutions whereby sewage sludge is incinerated and phosphorus is recovered from ashes. Combustion of the sludge entails loss of nutrients and carbon

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[4] In a way, the emergence of new risks pertaining to sewage sludge follows the way Beck (1992) describes the discovery of new environmental problems as our understanding of human interaction with nature improves.

but may be an effective means of purifying the sludge both physically and symbolically, as actually burning the sewage sludge could remove the “filth” connotation.

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