How can conflicts, complexities and uncertainties in a circular economy be handled?

A cross European study of the institutional conditions for sewage sludge and bottom ash utilization

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Final report of MISTRA Fellowship
2018

SUMMARY

The circulation of waste, where waste is given a new chance as a resource, can potentially replace the environmentally harmful extraction of virgin resources from the Earth crust. But at the same time, waste often contains higher levels of contamination than the corresponding material from the bedrock. Increased use of waste brings thus benefits at the global level, for example by reducing mining and carbon dioxide emissions, but at the same time, the disadvantages of increased levels of contamination affects primary locally.

This conflict has been exemplified in this study by looking closely at two different waste residues: bottom ash and sewage sludge, which contain both resources and hazards. In Sweden, the utilization of these residues is limited. In central Europe, on the other hand, several countries demonstrate a high utilization of waste.

The purpose of this study is to map the institutional conditions in Europe that may facilitate the use of waste, without increasing the risk. How can waste in terms of both its resources and hazards be handled in the best way? First, the challenges facing the use of bottom ash and sewage sludge are identified in Sweden. After that, the challenges are brought to Central Europe to see how they have handled the challenges in achieving a higher use of waste. Finally, the lessons learned from Europe are brought back to Sweden to discuss how the use of waste can increase through different political trajectories. The study is based on interviews with three different actors: waste producers, waste recipients and the authorities, mainly in three different countries: Sweden, Denmark and Germany.

CHALLANGES

- *Trust in the regulation is missing***.** All stakeholders express that current policy for using waste in Sweden is insufficient. The policy for using bottom ashes are too strict, and for the use of sewage sludge too liberal.
- *Uncertainty about future policies.* There are uncertainties about how future polices for bottom ashes and sewage sludge will be reformulated. Therefore, actors await costly investments.
- *Lack of institutional capacity.* The capacity to handle resources is low, as municipalities apply the policies differently.
- *Unbalanced resources policy.* Waste-based materials face much tougher requirements than conventional materials from the Earth's crust.
- *Lack of interest from the customer.* Potential customers see few reasons to use waste-based material instead of conventional virgin material.

- *Available alternatives***.** There are other waste-based alternatives more interesting to customers than sewage sludge and bottom ash.

FAVORABLE INSTITUIONAL CONDITIONS

- *Liberal guidelines***.** Liberal requirements for using waste may potentially increase its use, since a larger proportion of the generated waste will fall within the regulatory requirements.
- *Strict guidelines.* Strict requirements can potentially lead to increased use of waste, as reliability in the quality of the waste may increase among costumers.
- *Differentiated guidelines.* The use of waste can potentially increase with a flexible regulatory framework with requirements depending on the risk and level of pollution.
- *Political will and objectives***.** An outspoken political vision can create the necessary predictability for involved actors to meet, invest in learning and technology.
- *Neutral and coherent resource policy*. A neutral resource policy that does not differ geographically and geologically creates better market conditions for waste.
- *Cooperation between government and business.* Cooperation between government and business can increase the use of waste, if the authorities support the market, while business invest in learning and technology.
- *Acceptance and customer interest***.** Economically favorable conditions and technical qualifications can increase costumers' acceptance and interest in waste.

POLICY TRAJECTORIES

How can trust in the regulation increase?

- *Hazards in relation to masses or resources.* The limit values of contaminations for using waste can either be expressed according to masses (mg/kg) or according to resources (mg/ kg P).
- *Leaching concentrations or total concentrations.* The limit values of contamination can either be measured in terms of leaching concentrations and/or total concentrations.
- *Differentiated conditions based on the material or context.* Differentiated requirements for waste can be based on the context of the use and/or on the properties of the waste.
- *Limit values based on the risk or the waste.* The limit values can be constructed based on either a risk assessment or the characteristics of the waste.

How can the security increase for future policies?

- *Bottom-up or top-down formulated policies*. Policies for using waste can either be formulated between involved actors or formulated top down by authorities.
- *End of pipe or preventive solutions*. Solutions to increase the use of waste are typically either end of pipe, directing pollution away, or preventive, focusing on avoiding the generation of pollution at the source.
- *Incremental changes or social transitions*. The relationship of the solutions to the existing system can either be incremental or require a radical transformation of the system.
- *Requirements according to capacity or risk*. The requirements for using waste may be the same for all stakeholders (based on risk), or based on the capacity for investment.

How can the institutional capacity for waste as a resource increase?

- *Centralized or decentralized authority*. Criteria for using waste can either be decentralized where each region sets their own criteria or be centralized, where the same rules apply across the country.
- *Differentiated or similar policies for primary and secondary resources*. The requirements for primary and secondary resources can be shared or different.
- *Institutional fragmentation or coherence*. The responsibility of primary and secondary resources are typically divided between two different ministries (industry and environment), but can be shared under the same institutional structure.
- *Resource or waste oriented organizations*. There could be tradeoffs between cleaning the flows as effective as possible and acquire residues of good quality.
- *National or multilateral policy*. Waste polices are normally a national issue, but waste is traded in the international market. Waste polices in one country might thus affect the situation in another country.

How can costumers' willingness increase?

- *Financial compensation or investment*. Compensation is often required for costumers to accept waste, but the money could also be invested upstream in preventive work, to increase the quality.
- *Direct or indirect political governance*. The authorities normally interfere in the waste market by enforcing rules, but might also become an active part on the waste market as a costumer or through public procurement.
- *Waste as a hot topic or asleep*. Despite the same scientific understanding, the use of waste seems in some region to be politically debated while in other regions the debate is missing, which could affect the acceptance of using waste.

How can access to alternatives be handled?

- *A material or social challenge.* The transition to circular economy can be driven by uncertain resource availability or be a political decision.
- *Alternatives: primary material or secondary material.* Primary material with a high environmental impact can be substituted with either another primary material or by secondary material.
- *Same or different requirements for secondary material.* The requirements for using waste based resources can either be the same, like for waste used in constructions, or differ like between sewage sludge, manure and digestate.

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1. INTRODUCTION

One of the challenges of a circular economy is to increase the use of secondary resources at the expense of primary resources. This calls for fundamental societal change and in particular for policy makers and recycling operators (European Commission, 2015; Swedish Government, 2014). Our consumption of primary, virgin resources from the Earth's crust needs to decrease and stabilize at a much lower level. At the same time, the recycling sector needs to become a central producer of raw materials to maintain the welfare.

Environmentally-driven changes, for example, towards renewable fuels or circulating material flows, rarely have clear market benefits, or advantages for the user in terms of lower prices and higher performance (Geels, 2011). For this reason, different forms of political interference are typically required, which alters the “rules of the game” (North, 1990:3). Such institutional conditions work either directly in the form of, for example, subsidies or in longer term, for example, objectives (Johansson, 2016). By changing the institutional conditions of the environmental driven alternatives, in this case secondary resources, they may become more lucrative in the market.

The waste sector is one of the most regulated sectors through imposed laws, limit values, sanctions, incentives, and public monopolies. But these policies are primarily designed to control and regulate waste streams and emissions, to protect society, the environment and health from the negative impact of waste (Johansson & Corvellec, 2018). Less policy attention has been given to support increased circulation, where waste, in terms of resources, is given a central place to substitute primary production. Research within the field of *circular economy* is still potentially oriented to demonstrate its environment and job creation benefits (Andersen, 2007; Ghisellini et al., 2016), rather than understanding the role of institutions to maintain material in the economy.

However, beyond the obvious potential, there are consequences and conflicts in a circular economy. For example, embedded in the circular economy, there are conflicting policy objectives between decreasing toxic elements and increasing circulation of waste. The production of secondary minerals is generally regarded as more environmentally friendly than primary production, for example, less energy is required (UNEP, 2013). But at the same time, the production outcome, the very resource, from recycling rarely holds as low levels of heavy metals as primary resources (Johansson et al., 2017b) since it is present in more complex and heterogeneous compounds than the Earth's crust (Johansson et al ., 2013). This conflict derives from the differences between the conventional pollution driven waste policy to protect the environment from waste, and the emerging resource driven waste policy to support the circulation of waste (Johansson et al., 2017a). There is thus a risk that increased circulation of waste will lead to increased levels of heavy metals and other undesirable substances.

This conflict of interest can be exemplified by two types of residues: bottom ash from waste incineration and sewage sludge from municipal wastewater treatment plants, as they both contain a mix of resources and contaminants. These two residues are handled in different ways within the EU. In Sweden, all bottom ashes ends up at landfills, mainly as a cover material, while only a limited share of the nutrients in the sewage sludge are circulated through spreading practices on agricultural fields. However, a short trip across the Öresund Bridge between Sweden and Denmark brings a totally different situation. In Denmark, almost all produced bottom ash are used in road constructions (Hedenstedt, 2015), while more than 70% of the sewage sludge is applied to fields (Werther, 2012). Other central European countries such as Flanders in Belgium, the Netherlands, France and Germany shows also higher use of residual waste and stronger innovation in the field than Sweden (Saveyn, 2014; EPA, 2018).

The purpose of this report is to map various institutional arrangements in Europe that may facilitate the use of waste, focusing on sewage sludge and bottom ashes, without increasing the risk. How can waste in terms of both its embedded resources and hazards be handled in the best way? The study consists of three parts. First, the institutional challenges for increased use of sewage sludge and bottom ash are identified in Sweden. After that, the challenges have been brought to Central Europe to see how other countries have coped with the challenges in achieving a significantly higher use of waste. Finally, with the lessons learned from Europe, possible ways for Sweden to increase the use of waste are discussed by presenting different potential trajectories for resource and waste policies. The following research questions can be formulated:

- What are the institutional challenges to increase the use of bottom ashes and sewage sludge in Sweden?
- What institutional conditions have driven the use of bottom ashes and sewage sludge in Central Europe?

2. BACKGROUND

In this chapter the material focus on bottom ash and sewage sludge is presented. These two waste types are both industrial residual products. The use of these residues leads potentially to reduced primary production, while increased diffusion of undesirable substances.

2.1. Bottom ashes

The amount of incinerated waste in Sweden has increased. Between the year 2012 and 2016, the amount of incinerated waste increased with 17% from 5 million tonnes to 6 million tonnes (Avfall Sverige, 2018a), where industrial waste accounted for the increase. This also means that the residues from waste incineration in the form of ash increased. By 2017, about 1 million tonnes of *bottom ash* were generated from Swedish waste incinerators (Avfall Sverige, 2018a), which normally consists of non-combustible materials such as glassware, porcelain, and metals. In addition, waste incineration generates also another type of ash –*fly ash*- which is separated in the cleaning of airborne emissions, also referred to as APC residues. In 2016, fly ash amounted to approximately 288,000 tonnes (Avfall Sverige, 2018a).

Fly ash is usually classified as hazardous waste and is therefore deposited in specific landfills adapted for hazardous waste. The bottom ash is normally treated by removing scrap metals and larger objects (Avfall Sverige, 2018a). The residues from the treatment, the ash, are in Sweden used as a construction material on landfills, either to cover landfills or to build roads within the landfills. Bottom ashes have similar physical properties as natural gravel (Arm, 2006; Bend, 2006) and therefore in Sweden referred to as "slag gravel" (Swedish: slaggrus). A number of research projects have investigated the technical applicability of bottom ashes outside landfills, substituting natural gravel as construction materials in road structures (Arm, 2003; Ore, 2007; Avfall Sverige, 2015).

By using waste as ballast, the mining of natural gravel and sand can be reduced, including several advantages. Ballast is next to water the most extracted raw material in Sweden (SIG, 2018) and globally (USGS, 2011). The energy use for extracting sand and gravel from the bedrock is low compared to metal mining (Birgisdottir et al., 2007), since the need of processing the raw material into a resource is limited. The motive for preserving gravel and sand in the bedrock is the natural value of the deposits and its importance for ground water. In Sweden, gravel deposits constitute the most important groundwater magazines and can cover the water needs of many smaller communities (Miljömål, 2018). Removing gravel from these deposits will reduce the cleaning effect. In addition, mining practices can contaminate the groundwater, e.g. through oil spill. Therefore, reduced mining of gravel are linked to the

Swedish environmental objectives of " Groundwater of good quality ", precised by the Swedish government as "Natural gravel deposits of great importance [... should] be preserved" (Miljömål, 2018), which is echoed in the EUs Water Directive (EU, 2000).

The need for ballast material in Sweden is expected to increase. For example, Boverket (2016) estimates that 700,000 new homes will be needed in Sweden until 2025, which will require large amounts of ballast material for the foundation of buildings and infrastructure. SGU (2017) believes that the need for ballast material will increase by 60-70% annually, compared to the average for the period 2000-2015. In the year 2016, 56 % of all ballast was used in road structures (SGU, 2017).

The environmental concern of using bottom ashes in constructions is its high levels of hazards, Table 1. Some substances such as iron and aluminum with high concentrations in the Earth's crust have approximately the same concentrations in the bottom ash as in natural ballast material (Fällman et al, 1999). Substances used as main components in products, with lower concentrations in the bedrock such as copper, nickel, lead and zinc are often found in higher levels in bottom ash than natural ballast material.

Table 1. The mean values (mg/kg) of heavy metals in bottom ash (from moving grate), compared to mean values of the same elements in crushed rock.

	Total concentration		Leaching concentration (L/S 10)	
	Bottom ash	Crushed rock	Bottom ash	Crushed rock
Arsenic (As)	42,7	10	0.028	0.012
Cadmium (Cd)	7,07	0.36	0.0028	0.0045
Chromium (Cr)	504	43	0.324	0.08
Copper (Cu)	4260	27	6.14	<0.05
Nickel (Ni)	179	20	0.04	0.052
Leab (Pb)	1190	21	0.073	0.013
Zinc (Zn)	5100	70	0.364	0.058

Reference: Allaska, 2011; Ekvall et al 2006

The risk of heavy metals, however, depends not only on the total concentration, but also on how hard the elements is bound to the ash particles, the pH-value, storage time and the content of dissolved organic carbon (Flyhammar et al., 2004; Olsson et al., 2006). The leaching concentrations of heavy metals are more comparable between bottom ash and crushed rock, but with the exception of copper, table 1.

Regulation

The use of waste in Sweden is regulated by the Environmental Assessment Ordinance (SCS, 2013). Using waste in constructions that can pollute the environment requires a permit. The

Swedish EPA (Naturvårdsverket, 2010) has developed a guide for using waste for construction purposes. The guide presents possibilities for using waste as a construction material with no need of permission and criteria for using waste freely and as landfill cover, table 2. The presented levels are guiding values. In cases where the waste does not meet the guiding values, a specific risk analysis should be conducted for the local authorities to decide upon.

Table 2. Swedish criteria for using waste as a construction material

Substance	Free use		Landfill cover	
	Total (mg/kg)	Leaching mg/kg (10 l/kg)	Total (mg/kg)	Leaching mg/kg (10 l/kg)
Arsenic (As)	10	0,09	10	0,4
Cadmium (cd)	0,2	0,02	1,5	0,007
Chrome (cr)	40	1	80	0,3
Copper (cu)	40	0,8	80	0,6
Mercury (Hg)	0,1	0,01	1,8	0,01
Lead (Pb)	20	0,2	200	0,3
Nickel (Ni)	35	0,4	70	0,6
Zinc (Zn)	120	4	250	3

Reference: Naturvårdsverket, 2010.

There are several instruments that indirectly affect the possibility of using waste as a construction material such as the landfill tax, a tax of SEK 50o (€ 50) per tonne of landfilled waste, which steers towards finding a use for the waste (SCS, 1999). In addition, there is a tax on natural gravel of SEK 15 per tonne (SCS, 1995), to steer towards the use of alternative ballast materials. Since 2009, it is also harder to get a concession for opening gravel mines, as gravel deposits shall not be opened "when it is technically possible and economically reasonable to use another material" (SCS, 1998). There are also several technical requirements to use waste as construction materials in road construction, which relate to the load bearing capacity, stability, compression and durability of the material (Trafikverket, 2013).

State of the art

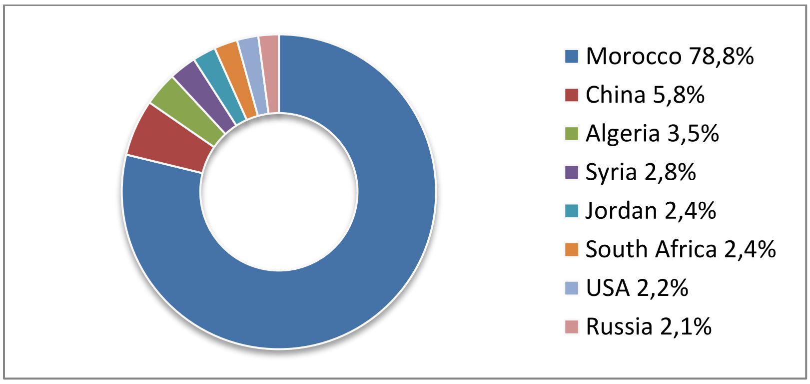
Previous research of bottom ashes as a construction material has primarily focused on its technical and environmental potential (Arm, 2006; Bend, 2006). Research on the institutional conditions of ash utilization typically compares the risk assessments and limit values of different countries (Saveyn, 2014). Other policy comparisons have highlighted the policies, instruments and fees in different countries (Wilhelmsson & Jansson, 2008; Hedenstedt, 2015) and successful cases of bottom ash application to infrastructure projects (Sahlin, 2013).

2.2. Sewage sludge

On average, each Swede uses about 140 liters of water per day (Svenskt vatten, 2018b). When this water flows into the sewer, mixed with the outside water from streets and industries, it is transported to municipal wastewater treatment plants, the “kidneys of our society” (Evans, 2011). At the plant, the waste water is mechanically, biologically and chemically treated to remove contaminants before the water reaches the recipient. The solid residues from the treatment are referred to as *sewage sludge* and contain mainly feces and other organic substances.

During the past 10 years, the production of sewage sludge has been relatively constant. In the year 2016, about 204,000 tonnes (TS) of municipal sewage sludge were produced in Sweden (SOS, 2018). The sewage sludge is usually further processed by various stabilization methods such as digestion (energy recovery) and dewatering. During the last ten years, about 30-35% of the sludge has been used as fertilizers in green areas such as public parks, 25% was sent to landfills, 25% was applied to farmland and the rest has been stored or used in other ways (SOS, 2018). However, in 2016 a change was observed as around 34% of the sludge was applied to arable land.

The argument for applying sewage sludge to arable land is primarily to reduce the use of mineral fertilizers, such as phosphorus, nitrogen and potassium. This transformation is driven by the unsustainable use of fossil phosphorus and nitrogen, which is likely to disturb Earth's natural cycles of the substances (Rockström et al., 2009). At the same time, estimations of the amount of remaining phosphorus in geological reserves are uncertain, some argue that peek phosphorus is within reach (Cordell & White, 2011), while others argue that the phosphorus reserves will last for more than several hundred years (Van Kauwenbergh, 2010). Regardless of the geological conditions, the accessibility of phosphorus is a growing concern, as around 90% of all phosphorus is controlled by only 5 countries (USGS, 2013), figure 1. More than ¾ of the economically phosphorus reservoirs are found in Morocco after they have annexed West Sahara in a conflicted occupation (UN, 2018), which has a generally high cadmium content (De Ridder et al., 2012). In addition, mineral fertilizer contains around 5-200 ppm Uranium (Yamazaki & Geraldo, 2003), which increase the levels of Uranium in arable land (Yamaguchi et al., 2009).



Reference: USGS, 2013

Figure 1. Global distribution of phosphate reserves (USGS, 2013)

Nitrogen is produced by capturing airborne nitrogen (N2) and transform it into NH3 by using fossil fuels in an energy-intensive process. The use of fossil nitrogen fertilizers is the second largest source of climate emissions from the Swedish agricultural, just after the diesel consumption of machines (Ahlgren, 2009). Globally, fossil nitrogen production requires about 1-2% of all energy use (Heffer and Prud'homme, 2016), using about 5% of the total production of natural gas in the process (Woods et al, 2010).

Globally, FAO (2017) estimates that the demand for fertilizers will increase annually by 1-2%. The future demand in Sweden is uncertain. Swedish arable land generally has no phosphorus deficiency, although there are regional differences (Naturvårdsverket, 2013). However, Sweden's population is growing. Furthermore, one of the overall goals of the Swedish food strategy is that "the total food production [shall] increase" (Sveriges regering, 2017). EU (2011) has also prioritized increased self-sufficiency of critical minerals such as phosphorus.

The problem of using sewage sludge as a fertilizer is the content of high levels of contaminations, Table 3. The level of many heavy metals in sewage sludge has decreased during the last 20-30 years (Naturvårdsverket, 2013). The content of most heavy metals such as cadmium, mercury, copper, lead and zinc is, however, still several times higher in sewage sludge than in mineral fertilizer, Table 3. Other elements, less highlighted, such as Cerium, Gadolinium, Neodym, Yttrium, have comparable levels between sludge and mineral fertilizers (Naturårdsverket, 2011). The level of some substances in the sludge are increasing, mirroring the increase in society (Olofsson, 2012). These substances are usually not found in mineral fertilizers such as drug residues, pathogens, micro plastics and organic pollutants such as PCDD/F and PAH (Naturvårdsverket, 2013; Miljødirektoratet, 2017).

Table 3. The average concentration of heavy metals (mg/kg P) in sewage sludge and mineral fertilizers

	Sewage sludge	Mineral fertilizer (NPK)	Mineral fertilizer (P20)
Cadmium (cd)	44	0,24	16
Copper (cu)	14000	6,9	310
Mercury (hg)	40	0,04	0,14
Lead (pb)	1500	2	25
Nickel (ni)	720	22	65
Zinc (zn)	25000	76	590

Reference: Naturvårdsverket, 2011

However, the availability of substances in the sludge does not only depend on the total concentration. The potential release of contaminations is determined by, for example, the type of seed, type of contamination and the pH-level of the soil. For example, Sternbeck & Österås (2013) review of previous studies showed an increased uptake of Copper, Zinc and Nickel in crops, while other substances such as Lead and Cadmium was not absorbed as consequences of sludge application to farmland. Furthermore, certain antibiotics can be absorbed by plants (Wegst-Uhrich et al., 2014), while other pharmaceuticals are broken down in the soil (Golet et al., 2003).

Regulation

To use sewage sludge in Sweden, the sludge must meet the requirements of 7 heavy metals (SCS, 1998), table 4. There are also ordinances, for example, on the maximum permitted level of heavy metals in soil, Table 4, (Naturvårdsverket, 1994; Jordbruksverket, 2004). The ordinances contain also a number of restrictions on using sewage sludge on pasture land and arable land. In practice, sewage sludge in Sweden is rarely applied to fields for food cultivation. Most of the sludge used in Swedish agriculture goes to energy crops, food exports and animal feed.

Table 4. Maximum concentration of heavy metals in sewage sludge applied to arable land (*sewage sludge*), max background levels in arable soil (*arable soil*) and maximum addition of heavy metals to arable land through sewage sludge (*addition*).

	Sewage sludge (mg/kg)	Arable soil (mg/kg)	Addition (gr/ha)
Cadmium (cd)	2	0,4	0,75
Copper (cu)	600	40	300
Mercury (hg)	2,5	0,3	1,5
Chrome (cr)	100	60	40
Lead (pb)	100	40	25
Nickel (ni)	50	30	25
Zinc (zn)	800	100	600

References: SCS, 1998; Naturvårdsverket, 1994

Since the year 2005, it has been forbidden to deposit sewage sludge in Sweden as a result of the ban on disposal of organic content exceeding 10% (SCS, 2001). Presently, an introduction of tax on cadmium is under discussion (SoU, 2017).

State of the art

Research on the application of sewage sludge to arable land has primarily focused on risks (Petrie, et al., 2015) and technology development for improved sewage sludge management (Zhang et al, 2017). The institutional conditions for sludge management have often been studied by comparing the limit values for sludge application (Mininni et al., 2015; Miljøstyrelsen, 2018b) or descriptively present the current policy (Spinosa, 2001). There are also studies looking into the controversy of sludge application to arable land, focusing on individual attitudes (Krogmann et al., 2001) or how actors can approach each other despite locked positions (Bengtsson & Tillman, 2004).

3. METHOD

This chapter presents how the study has been conducted with regard to selection and methods for collecting information

3.1. Selection of countries

The study of the institutional conditions for the utilization of bottom ash and sewage sludge focuses on three countries: Sweden, Germany and Denmark.

Sweden is the starting point of this study. The institutional conditions that prevent the use of bottom ashes and sewage sludge are identified in Sweden, as the use of these residual materials is limited in this country. In order to find out how the use of bottom ash and sewage sludge can increase, the identified challenges are brought to Central Europe to study how they have been managed in countries with higher levels of utilization. The two countries in Central Europe given most attention in this study are Denmark and Germany, both EU Member States just like Sweden.

Denmark has been selected since they use a high level of both sewage sludge and bottom ash. Almost all bottom ashes are used as sub base course in road constructions (Hedenstedt, 2015) while over 70% of the sludge is applied to arable land (Werther, 2012). Germany has been selected partly because of the high use of bottom ashes (Hedenstedt, 2015) and sewage sludge (Umweltbundesamt, 2018) in certain regions. However, the main reason for a specific focus on Germany is the development of new innovative policies for the management of sewage sludge and bottom ash. In Germany, it will become partially prohibited to apply sludge on fields. Phosphorus shall instead be extracted, when the content is high enough (BMU, 2017). A new law on the utilization of waste as construction materials is also being prepared in Germany (Umweltbundesamt, 2017).

In addition to the study of Germany and Denmark, the institutional conditions have also been studied in other European countries. Other countries included in the study are the Netherlands, Flanders (Belgium), Finland, Norway, Spain and France. Information from these countries has been included in the study when mentioned as interesting in the study of Sweden, Denmark and Germany.

3.2. Collection of information

Information has been collected through two different methods; interviews and supplementary document analysis. Interviews were the main source for mapping the institutional conditions, while document analyzes have supplemented the interviews.

Interviews

In order to map the institutional conditions of the included countries, interviews were conducted with three different groups of actors; (1) waste producers, potential (2) waste recipients and the (3) authority. These three actors have been selected because they are the most important stakeholders in the waste market (cf. Johansson et al., 2017b), i.e. the seller (waste producer), the customer (waste recipient) and authority (which sets the rules for the market). For bottom ashes, waste incinerators are the main waste producer, while the agency responsible for infrastructure is the potential customer. The Environmental Protect Agency (EPA) is the responsibly authority in both cases. For sewage sludge, sewage treatment plants are the waste producer, while farmers the potential customer. In this study, to represent the waste water treatment plants, a consultant from Nitoves AB, working at that time at the Swedish Water & Wastewater Association (Svenskt vatten) was singled out as a representative. It was only in Sweden, Germany and Denmark where all stakeholder groups were approached. In the other countries, the selection of respondents was chosen based on tips from the respondents from the three emphasized countries.

In most cases, representatives of the industry organizations were interviewed, which meant that, for example, representatives of the farmers' federations in Sweden, Denmark and Germany were interviewed. The respondents are presented in Table 5 and 6. In cases when the organizations pointed out several representatives, two people were interviewed in the same organization. In some cases, the authorities did not respond to the interview request. In order to get a comprehensive picture, in these cases, supplementary interviews were made with researchers or NGOs in the same country.

Table 5. Respondents in the study of bottom ash, divided according to stakeholder groups and country.

	Sweden	Denmark	Germany	Finland	Netherlands
Waste producer	- Avfall Sverige	- Afatek A/S	- ITAD	Erityisjate	- Vereniging Afvalbedrijven
Waste receiver	- Trafikverket 1 - Trafikverket 2	- Vejdirektoratet	- BASt	-	-
Authority	Naturvårdsverket	-	- Umwelt bundesamt	-	-
Additional	-	- Danish Waste Solutions	-	-	-

ITAD= Interessengemeinschaft der Thermischen Abfallbehandlungsanlagen in Deutschland
BASt= Bundesanstalt für Straßenwesen

Table 6. Respondents in the study of sewage sludge, divided according to stakeholder groups and country.

	Sweden	Denmark	Germany	Netherlands
Waste producer	- Nitoves AB - HD Biorec	- Hede Denmark	-DWA	- SNB
Waste receiver	- LRF 1 - LRF 2	- Landbrug & Fødevarer	Deutscher Bauernverband	-
Authority	Naturvårdsverket	-	-	-
Additional	-	-Jes la Cour Jansen ApS	- DPP - Isle utilities - KWB	-Nutrient Platform

DWA= Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall
KWB= Kompetenzzentrum Wasser Berlin
SNB= Slibverwerking Noord-Brabant
DPP= Deutsche phosphor-platform DPP

In addition to interviews in Sweden, Denmark and Germany, actors in Finland and the Netherlands were also approached, Tables 5 and 6. In Finland, a representative of bottom-ash producers (*Erityisjate*) were interviewed, who was involved in the new finish legislation (Finish government, 2017) for the utilization of waste as a construction material. In the Netherlands, representatives of the Dutch Waste Management Association (*Vereniging Afvalbedrijven*), a sewage sludge producer (*SNB*), and a NGO (*Nutrient Platform*) involved in the management of sewage sludge were interviewed.

The questions were formulated differently to the respondents in Sweden and the other countries. The interviews in Sweden were designed to identify challenges for increased use of bottom ash and sewage sludge. Examples of questions to the Swedish respondents were: why is the use of sludge/ash limited in Sweden? What are the pros and cons of increased waste utilization? Interviews in other countries were primarily undertaken to understand what has enabled increased utilization of sludge/ash in these countries and how they coped with the challenges identified in Sweden. Examples of questions to these respondents were: What aspects have been crucial to realize the utilization of ash/sludge? How have the benefits of using waste been balanced against the risks? Why has the costumers accepted waste based materials instead of the conventional resources? Most interviews were performed over the phone. Interviews with the German, Finish and Dutch actors were held in English, while the interviews in Sweden and Denmark were in Swedish. All respondents were offered to control their quotes in this report.

Document analysis

Almost all interviews drew attention to how the national regulations affect the use of bottom ash and sewage sludge. Therefore, a simplified mapping of the regulations was performed of the policy for using bottom ashes and sewage sludge in Sweden, Denmark, Germany, Finland

and the Netherlands. The document analyzes were made partly to validate the information mentioned in the interviews, partly to map and compare regulations and limit values for using waste in different countries. Mapping the limit values for the use of bottom ashes included also the Flemish criteria, while the application of sewage sludge to arable lands included the criteria of France, Spain and Norway, after being identified by the respondents as interesting.

3.1. Analysis

The interviews were analyzed by identifying reoccurring themes, which categorized the content of the interviews into different groups. From the interviews with the actors in Sweden, six different themes were identified in the form of challenges for increased use of sludge and bottom ash, which are presented as headings in Chapter 4. From the interviews with stakeholders outside Sweden, mainly Central Europe, seven different themes could be identified facilitating the use of sewage sludge and bottom ashes, which are reported as headings in Chapter 5. Finally, in Chapter 6, the two above mentioned chapters are brought together in a discussion of how the challenges can be addressed by visualizing different potential trajectories for policy makers.

References to the interviews with stakeholders are presented in the report by quotes and derived to the specific respondents by presenting the respondent's organization in italics within parentheses. References to the document analysis are presented in accordance with the Harvard reference system with surname of the author and year of publication.

4. CHALLENGES FOR WASTE UTILIZATION

In this chapter, the challenges are presented for increased use of sewage sludge and bottom ash. Each heading represents a challenge. Under each heading a more detailed description is given of the challenges for increased utilization of bottom ashes and sewage sludge.

4.1. Trust in the regulations is missing

Both producers and potential recipients of sewage sludge and bottom ash express that the current legislation is insufficient. Lack of trust decreases the interest of using waste as a raw material.

Ashes

All interviewed stakeholders in Sweden consider that the current legislation for using waste in constructions is insufficient. Representatives of the municipal incineration plants in Sweden argues that the criteria for using waste is not adapted to how waste will potentially be used in constructions. There are limit values only for “the use of waste without any protection or insulation, which is not how bottom ashes would be used in constructions” (*Avfall Sverige*). Also the potential recipient and user of bottom ashes, the Swedish Transport Administration, responsible for the major infrastructure projects, are skeptical to the current legislation as "we do not know when, how or where it is okay to use different waste based construction materials" (*Trafikverket 1*). Overall, the regulations for using waste as construction materials appear to have been "difficult to apply for officials and practitioners" (*Naturvårdsverket 1*). The lack of trust in the regulations for using waste in constructions are confirmed by the Swedish EPA’s (2015) own evaluation, which states that the use of waste in constructions has decreased rather than increased as an effect of the current regulation.

Sludge

A representative of the Swedish wastewater treatment plants argues that the "legislation for application of sewage sludge is insufficient" (*Nitoves AB*), which the farmers’ federation in Sweden, the potential recipient, agrees with as it is "very difficult to accept sewage sludge based on the prevailing legislation" (*LRF 1*). The background is that the current legislation regulates the application of sewage sludge through only 7 different trace elements (SCS, 1998), while virtually the entire periodic system can be found in sewage sludge (EPA, 2011). This means that sludge could be approved according to the regulation, but may contain hazardous levels of elements that are not controlled. Due to the insufficient legislation, waste water treatment plants and the farmer federation have in Sweden entered into an agreement (REVAQ) with significantly tougher requirements, which regulate 60 different elements (REVAQ, 2018).

4.2. Uncertainty about future policies

There are uncertainties about how future polices for bottom ash and sewage sludge will be reformulated. As there are many different political trajectories, involved actors postpone costly investments that potentially can increase the use of waste.

Ashes

The EU (2017) has introduced a new method for classifying hazardous waste in 2018 by implementing a new assessment criterion for ecotoxicity. A consequence of this may be that bottom ashes, which today is classified as non-hazardous waste may be reclassified into hazardous waste. If bottom ashes are classified as hazardous waste, the use of this material in the society may become significantly more complicated or as the potential recipient argues; "If the material is classified as hazardous waste, then there is no idea, the permission process [for using bottom ashes in road construction] will become even more complicated" (*Trafikverket 1*). For this reason, the waste producer awaits "a national decision on this matter, before proceeding [with finding outlets] (*Avfall Sverige*).

Sludge

The Swedish legislation for applying sewage sludge on arable land is from the mid-1990s (Naturvårdsverket, 1994; SCS, 1998), while the EU's (1986) sludge directive is from the mid-1980s. Since then, several policy investigations of the future management of sewage sludge have been conducted in Sweden. The latest report by the Swedish EPA (Naturvårdsverket, 2013) proposed new legislation with tougher limit values. A change of legislation is thus to be expected, but a decision has not yet been taken. Sludge producers have "waited a long time for new legislation" (*Nitoves AB*) and the potential recipient "awaits a clear political goal for increased phosphorus recovery and technology development" (*LRF 1*). There are thus uncertainties about the future management of sewage sludge: Should sludge be incinerated or applied to fields? What limit values will be applied? Will phosphorus recovery be a requirement? Or shall the sewage system be separated according different waste water flows? While awaiting new policies, there is no interest in making critical investments. Any investments in the sewage system will in the end effect the households through the fee on water and sewage. Due to the potential increased costs for households, it is currently "difficult to justify any investments that go beyond what the law requires" (*LRF 1*).

4.3. Lack of institutional capacity

There is low institutional capacity to handle waste as a resource. For example, policies are implemented differently in different municipalities. The consequence is that the predictability of using waste as a resource decreases.

Ashes

Bottom ashes rarely reach the criteria for free use, since “the total concentrations are too high” (*Avfall Sverige*). This means that every time bottom ashes shall be used, the local authorities needs to make a case specific approval. The consequences has been that "different interpretations [on the environmental risks of using bottom ashes] have been made in different municipalities" (*Avfall Sverige*) and in some cases "the regulations have been interpreted too strictly" (*Naturvårdsverket 1*). In some municipalities, the use of waste as a construction material is rare, which makes it difficult for small municipalities to build up capacity and expertise to handle applications. The different interpretations of the municipalities mean that the customer "cannot know in advance if the use of waste will be authorized” (*Trafikverket 1*). The capacity to handle waste based material in constructions appears also to be missing at the national level. For example, the Swedish Geological Survey, which is responsible for estimating available ballast materials, looks only at material in the bedrock in their compilations of available Swedish construction materials (SGU, 2017).

Sludge

The attitude of applying sewage sludge to fields is divided among the Swedish authorities. The Swedish Chemicals Agency (Kemikalieinspektionen, 2014) as well as the Swedish Medical Products Agency (Läkemedelsverket, 2014) are uncertain or negative toward using sewage sludge as a fertilizer, while the Swedish EPA (2013) is positive. The background to the different perspectives is the different policy responsibilities of the authorities. The Swedish EPA is responsible for recycling, while the Chemicals Agency is responsible for the diffusion of chemicals. The ambiguity among the authorities contributes to "an openness for municipalities to locally take their own decisions" (*HD Biorec*). Most municipalities are positive towards sludge as a fertilizer, but there are several municipalities, especially in southern Sweden, which are negative to sludge application and tries to stop it by local decision (Mark och Miljööverdomstolen, 2014) or dissuasion (ATL, 2016).

4.4. Unbalanced resource policy

Waste-based materials face much tougher requirements than conventional materials from the Earth's crust. As a consequence, it becomes more difficult for waste-based materials to compete in the market.

Ashes

To use waste-based construction materials such as bottom ashes, documentation, monitoring and permission from the authorities are typically required (SCS, 2013). However, in order to use conventional materials like natural gravel in road structures, no permit or monitoring of hazardousness is required. This means, according to the potential customer, that "the application for using waste based construction material takes extra time, which costs money" (*Trafikverket 1*). Furthermore, the Swedish Transport Administration (2013a) has developed ordinances that only concern waste-based materials, including, for example, criteria on maximum sulfur concentrations, which is not valid for conventional natural materials. The use of virgin materials is controlled by REACH (EU, 2006).

Sludge

The control of 7 different heavy metals for applying sewage sludge on fields does not apply to mineral fertilizers. The only environmental-related requirement for mineral fertilizers is that it shall contain less than 100 grams of cadmium per kilo of phosphorus (SCS, 1998). In addition, there is no requirement on the farmland the mineral fertilizer shall be applied to, which is the case for sewage sludge. Furthermore, the requirements for using different waste-based fertilizers vary. To spread digestate on arable land the requirements are similar to those for sewage sludge (Avfall Sverige, 2018b). The application of manure, on the other hand, is not regulated by contamination but, for example, the time of the year it may be applied (Jordbruksverket, 2004; 2013).

4.5. Lack of interest from the customer

Customers that shall receive the waste do not see enough benefits for using the material. Even if polices will change, it is uncertain if the interest of the customers will increase.

Ashes

Sweden's ambition to reach zero net emissions of greenhouse gases until 2045 is a "high priority" (*Trafikverket 2*) of the potential customer of bottom ashes, the Transport Administration. However, the infrastructure bears only a small proportion of the climate impact of transportation, about 5-10%, deriving from work machines and materials such as concrete, steel and asphalt (Trafikverket, 2017). Finding alternatives to ballast material is not a prioritized area, since the above mentioned materials (concrete, steel and asphalt) have a bigger climate footprint (Trafikverket, 2017). Therefore, "substituting other materials [than ballast] are more prioritized for reaching the climate goals" (*Trafikverket* 2). A further ambition of the potential customer is to reduce the amount of contaminants in their infrastructure (Trafikverket, 2017), which "may become harder to reach when using alternative materials such as bottom ashes" (*Trafikverket 1*).

Sludge

The farmers' federation argues that the application of sewage sludge to arable land, even through the REVAQ certification with its tougher criteria, has "reached its end" (*LRF 2*) as "sludge will never be a sustainable alternative, with today's infrastructure [which mixes all the waste water]" *(LRF 1*). The content of contaminants in the sewage sludge is partially uncertain as the sewage treatment plants cannot completely control the inflow. Sewage treatment plants can partly impose demands upstream on industries, but "find it harder to put demands on households, and, for example, their use of medication" (*Nitoves AB*). Although REVAQ (2018) demands the control of 60 elements, "effects of any compounds or medications" (*LRF 1*) are not measured. At the same time, the downstream costumers of farmers, the food industry, has "nothing to gain from the application of sewage sludge. It would hardly benefit their sales of food. Why should they then take a risk? "(*LRF 2*). The customers' attitude towards the use of sewage sludge affects the farmers' possibility of finding an outlet of their plants. In addition, the farmers' federation is uncertain about the quality of sewage sludge as a fertilizer. The coagulation of phosphorus with chemicals at the sewage treatment plants "decreases the plant availability of phosphorus in the sludge" (*LRF 1*). Therefore, farmers, who use sludge as fertilizers "needs normally to complement with mineral fertilizers" (*LRF 1*).

4.6 Available alternatives

There are other waste-based alternatives to mineral fertilizers and ballast materials that are more interesting to customers than sewage sludge and bottom ash, respectively.

Ashes

Even if the Swedish Transport Administration, the potential user of bottom ashes would prioritize substituting natural ballast material with waste-based alternatives, it is highly uncertain if bottom ashes would be of interest. For example, the Transport Administration has developed technical ordinances that regulates how and when different waste based alternatives such as blast furnace slag, crushed concrete and recovered asphalt can be used in road structures (Trafikverket, 2013). The experience of using slag and recovered asphalt in road constructions dates "back to at least the 1970s" (*Trafikverket* 1). Crushed concrete is rarely used today, but it is "a waste that will arise internally as concrete foundations will be demolished, which will then become a useful waste for us" (*Trafikverket 1*). In addition, the Transport Administration is uncertain of the quality of bottom ashes, as it has "an uneven composition compared to slag from smelters, due to the unpredictable inflow to the incinerators" (*Trafikverket 1*). In addition, there is today an outlet for bottom ashes in the form of covering landfills, ”waste producers have therefore under a long time had a clear idea where to deposit their waste" (*Avfall Sverige*). However, the demand for materials to cap landfills decreases, as most dumps will be covered within the next 10 years (Avfall Sverige, 2017).

Sludge

Representatives of the farmers' federation argues that "manure from barns and digestate from biogas production, is preferable to sewage sludge. Since manure and digestate derives from a controlled inflow, unlike sewage sludge "(*LRF 1*). The inflow of waste into biogas plants includes mainly food waste, slaughter waste, and energy crops (Feiz, 2016). Manure is usually controlled because "the farmer knows what he/she has put into the animals. Typically, manure is spread on the farmers own land, and the farmer can thus determine its sufficiency" (*LRF 1*). According to the farmers' federation, the availability of phosphorus is "higher in manure and biogas since phosphorus has not been coagulated by adding chemicals at the sewage treatment plants" (*LRF 1*). Previous studies show also that the uptake of phosphorus in plants is adversely affected by coagulation, the level of moisture in the sludge and the pH-level in the soil (Lemming et al., 2017; Kahiluoto et al., 2015).

5. INSTITUIONAL CONDITIONS FOR INCREASED WASTE UTILIZATION

In this chapter, the institutional conditions that have facilitated the utilization of bottom ash and sewage sludge are presented. None of the institutional arrangements can alone explain the increased use of waste, but should be understood together.

5.1. Liberal guidelines

Liberal requirements for using waste may potentially increase its use, since a larger proportion of the generated waste will fall within the regulatory requirements.

Ashes

A comparison between the requirements for using waste as a construction material in Sweden with countries like Belgian Flanders and Denmark with significantly higher use of waste in constructions, Table 7, shows that these countries have more liberal levels of heavy metals. For example, using waste as construction material without special permission, the total level of copper needs to be 12 times lower in Sweden than in Denmark, while the total level of lead need to be 60 times lower in Sweden than in Flanders.

Table 7. Maximum levels of heavy metals for free use of waste as a construction material. Total concentrations (mg/kg).

Substance	Sweden	Denmark	Flanders
Arsenic (as)	10	20	250
Cadmium (cd)	0,2	0,5	10
Chrome (cr)	40	20	1250
Copper (cu)	40	500	375
Mercury (hg)	0,1	1	5
Lead (pb)	20	40	1250
Nickel (ni)	35	30	250
Zinc (zn)	120	500	1250
Use in roads (2015)	< 5 %	100 %	40 %

References: Naturvårdsverket, 2010; Miljøstyrelsen, 2016; Flemish government, 2012: Hedenstedt, 2015

Sludge

A comparison of the maximum concentrations of heavy metals for applying sewage sludge to arable land in Sweden with countries such as France and Spain, which apply a significantly higher level of sewage sludge to arable land, Table 8, shows that EU's (1986) sludge directive have been implemented in different ways. For example, in order to apply sewage sludge to arable land, the level of cadmium needs to be 10 and 20 times lower in Sweden than in France and Spain, respectively.

Table 8. Limit values for applying sewage sludge to arable land. Total concentrations. (mg/kg)

Substance	Sweden	France	Spain
Cadmium (cd)	2	20	40
Copper (cu)	600	1000	1750
Mercury (hg)	2,5	10	25
Lead (pb)	100	800	1200
Nickel (ni)	50	200	400
Zinc (zn)	800	3000	4000
Use in farming (2010)	25 %	74 %	92 %

References: Mininni et al., 2015; Eurostat, 2018

5.2. Strict guidelines

Also strict requirements can potentially lead to increased use of waste, as the reliability in the quality of the waste may increase among costumers and other stakeholders.

Ashes

The use of waste as a construction material is governed not only by total levels but also by leaching concentrations. A further analysis of the requirements of using waste as a construction material shows that while the Danish and Flemish rules are more liberal with total concentrations (table 7), the allowed concentrations for leaching of heavy metals such as chromium, copper and zinc are lower in Flanders and Denmark than Sweden, table 9. This comparison shows that Denmark and Flanders control the use of waste through strict leaching criteria rather than through a focus on total concentration.

Table 9. Maximum leaching concentrations for free use of waste as a construction material (mg/kg).

Substance	LS 10 Mg/kg		LS 2 Mg/kg*	
	Sweden	Flanders	Sweden	Denmark
Arsenic (as)	0,09	0,8	0,019	0,016
Cadmium (cd)	0,02	0,03	0,0077	0,004
Chrome (cr)	1	0,5	0,28	0,02
Copper (cu)	0,8	0,5	0,23	0,09
Mercury (hg)	0,01	0,02	0,0018	0,0002
Lead (pb)	0,2	1,3	0,060	0,02
Nickel (ni)	0,4	0,75	0,12	0,02
Zinc (zn)	4	2,8	1,2	0,2

* Data transformed into comparable units by Ole Hjelmar

References: Naturvårdsverket, 2010; Miljøstyrelsen, 2016; Flemish government, 2012.

Sludge

A comparison between the Swedish and Danish limit values for applying sewage sludge to arable land demonstrates that the Danish levels of substances, identified as particularly toxic at low levels, in the form of cadmium and mercury are considerably tougher in Denmark, table 10. Denmark uses a higher share of their sewage sludge as a fertilizer than Sweden. According to *Hede Denmark*, "the strict requirements on sewage sludge have been crucial for realizing the high use of sewage sludge in arable fields", as these have created "a high trust in sewage sludge among all stakeholders".

Table 10. Limit values for applying sewage sludge to arable land. Total concentrations. (mg/kg)

Substance	Sweden	Denmark
Cadmium (cd)	2	0,8
Copper (cu)	600	1000
Mercury (hg)	2,5	0,8
Lead (pb)	100	120
Nickel (ni)	50	30
Zinc (zn)	800	4000
Use in farming (2010)	25 %	70 %

References: Werther, 2012; Mininni et al, 2015; Eurostat, 2018

5.3. Differentiated guidelines

The use of waste can potentially increase with a flexible regulatory framework with requirements depending on the risk and level of pollution.

Ashes

In countries where waste is commonly used as construction materials, there is a regulatory framework with a number of different categories that allow different use of waste depending on the level of pollution. For example, waste with higher levels of pollutants may be used in lower-risk environments, such as the sub base of a parking lot, while the requirements are higher for using waste beneath a daycare. Purer waste can be used freely, while the use of more polluted waste comes with different precautionary measures. For example, requirements on distance to groundwater, water drainage, insulation, thickness, dilution, monitoring and take back (Umveltbundesamt 2003; Miljøstyrelsen, 2016; Finish Government, 2017). In the Netherlands, quite high levels of hazards in the waste are allowed if it is used isolated in the lowest body of the road structure, figure 2.

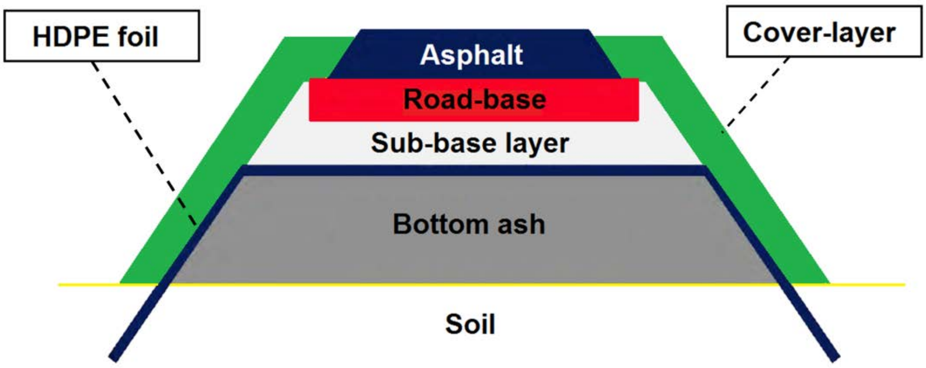


Figure 2. An overview of how bottom ashes are commonly used isolated in road constructions in the Netherlands. Adapted from Lamers (2015).

There are several alternatives for constructing a flexible regulatory framework for waste:

- *General categories*. In Denmark (Miljøstyrelsen, 2016) and Germany (Umveltbundesamt, 2003), there are three general categories (1,2,3) that are defined according to the level of pollution in the waste, including different precautionary measures.
- *Permeability*. In Flanders (Flemish government, 2012), the categories and requirements are divided depending on whether the material is monolithic, preventing water penetration (bounded) or if it consists of particulates, loose material that does not hold together (unbound material).
- *Isolation*. In Neatherlands (Rijkswaterstaat Water, 2007) and Finland (Finish government, 2017) the categories are divided depending on if the waste is used openly or covered in isolation, for example in a road structures, according figure 1.
- *Use*. In Finland (Finish Government, 2017), the limits of heavy metals differ depending on the context and specific use of the waste. Different limits are applied to using waste in roads, walls, or geo-constructions.
- *Origin*. In the forthcoming German legislation (Umweltbundesamt, 2017), the categories are defined by material type, such as bottom ash, slag or sludge. This legislation differs from the other countries as the requirements differ depending on the material type.

Tables visualizing the categories and its associated limit values are presented in Appendix 1

Sludge

Differentiated requirements in connection to pollution levels are not as common for sewage sludge as for waste based construction material. However, the application of sewage sludge, just like the use of waste in structures, is usually associated with a variety of precautions to reduce the risk. For example, restrictions in relation to specific crops, time of application, quantity, areas (reserves), distance to groundwater and nitrogen content (Miljøstyrelsen, 2017; Umweltbundesamt, 2017). In Norway, where about 66% of all sewage sludge is applied to arable land (Miljøstyrelsen, 2018b), there are differentiated requirements for sewage sludge depending on the pollution level. Norwegian legislation divides the use of sewage sludge into four different classes depending on the content of heavy metals, Table 11. The classes decides the amount of sludge that can be applied and where. Class 3 may only be applied on green areas and parks, not on farmland (Norsk Vann, 2008).

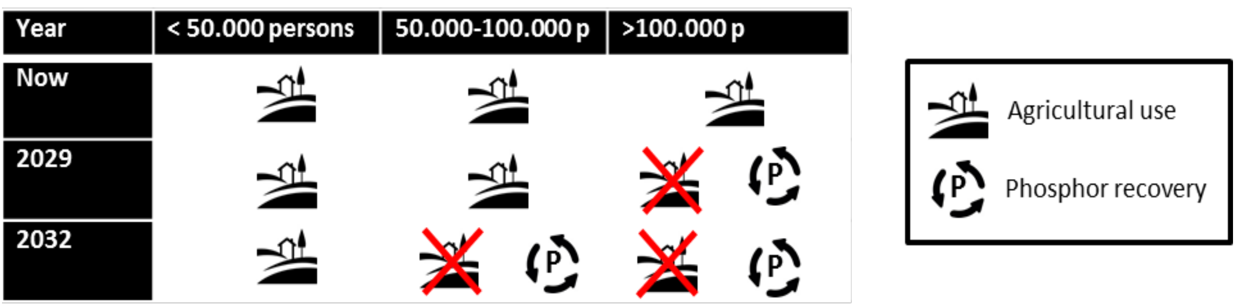
Table 11. Norwegian limits for using sludge, presented according to different classes. Total concentrations (mg/kg).

Substance	Class 0	Class I	Class II	Class III
Cadmium (cd)	0,4	0,8	2	5
Copper (cu)	50	150	650	1000
Mercury (hg)	0,2	0,6	3	5
Lead (pb)	40	60	80	200
Nickel (ni)	20	30	50	80
Zinc (zn)	150	400	800	1500

References: Norsk Vann, 2008; Miljøstyrelsen, 2018a

The requirements in Germany for phosphorus recovery from sewage sludge are "differentiated depending on the number of people connected to the waste water treatment plants" (*Isle*), Table 12. The largest sewage treatment plants serving more than 100,000 people shall recover phosphorus from the year 2029. The corresponding year for the medium sized plants (50,000-100,000 people) is 2032 (BMU, 2017). Small sewage treatment plants serving fewer than 50,000 people will continuously be allowed to apply sludge on fields in the future (BMU, 2017). The requirements in Germany for phosphorus recovery are thus not differentiated according to pollutant content, but the financial potential for investment.

Table 12. The requirements for sewage sludge management for Germany, differing depending on the number of connected persons to wastewater treatment plants.



Reference: BMU, 2017

5.4. Political will and objectives

An outspoken political will towards a specific vision can create the necessary predictability for involved actors to meet, invest in learning and technology for long-term change.

Ashes

Quantitatively formulated targets can indirectly enhance the capacity of the authorities to handle waste as a resource. In the Danish waste plan for the period 1998-2004, one of the targets was to utilize at least 70% of the residues from waste incineration (Miljøstyrelsen, 1999). These early targets for using bottom ashes as construction materials established a positive organizational culture towards bottom ashes within the Danish authorities. The Danish Road Directorate facilitated the use of bottom ash as a consequence of the above mentioned target by "continuous testing and development of criteria for how ashes should be used" (*Vejdirektoratet*).

General, unspecified objectives, such as promoting the circular economy, can also play a decisive role for increasing the use of waste. In formulating a differentiated regulatory framework in Finland for the use of waste as a construction material, "the objective of circular economy created a pressure on all actors to meet" (*Erityisjate*) and agree on how a regulation should be formulated.

Sludge

In Germany, the decision on phosphorus recovery and ban on land application of sludge created "a long-awaited clarity for wastewater treatment plants as well as farmers in an uncertain issue" (*KWB*). Sludge management was a controversial issue in Germany, since the authorities in northern and southern part of the country preferred different approaches; land application and incineration, respectively. The conflicting positions created a protracted policy process. Therefore, "just the decision in itself was more awaited, than the actual direction of the decision" (*Isle*).

The long transition period before the new requirements will apply (Table 12) was a "political compromise" (*DPP*) to give time for those who favored land application to change practices and build capacity for incineration. Another purpose of the transition period is to trigger learning processes and technology development of phosphorus recovery from ash, which "currently has an uncertain business potential" (*Isle*).

Unlike Germany, phosphorus recovery in the Netherlands has not been pursued through national policies. Instead, recovery of phosphorus seems to have been driven by the waste water treatment plants themselves, which no longer only perceive themselves as a station for decontamination but also a "energy and resource factory" (*Nutrient Platform*). However, indirectly, policy has played an import role for the organization to reformulate its purpose. The discharge requirements for wastewater treatment plants in the Netherlands are "formulated on an annual basis, which opens up for biological treatment and the crystallization of pure phosphorus to struvite" (*Isle*), which can be sold as a waste-based fertilizer. In Sweden and Germany, “the discharge conditions are formulated in monthly average, which can hardly be met by biological treatment” (*Isle*)

5.5. Neutral and coherent resource policy

A neutral resource policy that does not differ geographically and geologically, between regions as well as the origin of the materials, respectively, creates better market conditions for waste.

Ashes

In Belgian Flanders, Finland, Netherlands, Denmark and other countries where ashes are used as a construction material, the rules and guidelines are centralized, i.e. the same rules applies in the whole nation. The requirements for using ashes in these countries have been predictable, not depending on the attitude of local authorities. This allows "actors to know in advance if a waste material can be used in constructions" (*Danish Waste Solutions*), while avoiding the time consuming application process.

In the Netherlands, the rules to use primary and secondary materials as construction material have been shared since the year 1995 through the Dutch Building Materials Decree (PBL, 1995). This means the same requirements apply regardless of where the material comes from. Contaminated primary material, just like secondary material, needs to be encapsulated and insulated from water if it is to be used as a construction material. And vice versa; pure secondary material can just as primary material be used without restrictions. The advantage of the same requirements for secondary and primary materials is that "primary aggregates are not given competitive advantages, following lower prices" (*SNB*).

Sludge

In Denmark with a high proportion of sewage sludge application to arable land, "authorities and other societal actors seem to agree that this is a worthwhile practice" (*la Cour Jansen*). Unlike Sweden, chemicals do not have their own agency in Denmark, but are under the responsibility of the Danish EPA (Miljøstyrelsen, 2018b). So, even if there are internal conflicts, for example if recycling or chemical prevention shall be given priority, there is no ambiguity between two different authorities in Denmark, like in Sweden where chemicals and recycling are the responsibility of two different agencies. Instead, communication and the policy of sludge management are consistent towards the public.

In Germany, the legal requirements for waste based and primary fertilizers are shared since 2012 (Umwelstbundesamt, 2012). The highest permitted levels of heavy metals such as cadmium, copper, mercury, nickel and lead are the same, Table 13. However, during the last years, the legal requirements for waste-based fertilizers have become stricter in the form of, for example, limits on PCB, AOX, B(a)P, nitrogen content and requirements for phosphorus recovery, which is not the case for primary fertilizers.

Table 13. Regulation for primary and secondary fertilizers in Germany

Substance	Primary	Secondary
Cadmium (cd)	1,5	1,5
Copper (cu)	900	900
Mercury (Hg)	1,0	1,0
Lead (Pb)	150	150
Nickel (Ni)	80	80
Zinc (Zn)	4500	4000
Nitrogen (N)	-	170 kg N/ha
Phospor extraction	-	Yes

References: Umweltbundesamt, 2012; 2017.

5.6. Cooperation between government and business

Cooperation between government and business can increase the use of waste, if the authorities support the market, while business invest in learning and technology.

Ashes

In addition to creating policy instruments such as bans and taxation, in order to steer the flows of material, the authorities can also become an active part of the value chain. In Denmark and the Netherlands, the national transport authorities, responsible for infrastructure, are using bottom ashes as a sub-base material "in case there is a suitable project and sufficient amount of ash available" (*Vejdirektoratet*). Thereby, the authorities creates a market for the waste, and by demonstrating the usefulness of ashes, the uncertainties inherent in a new unconventional material are reduced.

The political approach of the Netherlands is to first give societal actors an opportunity "to solve an environmental problem in a way that suits them best, before the government forces strict regulation to tackle the problem” (*Nutrient Platform*). Environmental problems are commonly addressed through agreements between private actors and the national authorities in what is referred to as *Green Deals*. The principle of the agreement is usually that the private operator identifies obstacles that need to be removed to address the environmental problem, while the state puts additional demands on the private operator (Green Deal, 2015), thereby allowing "both partners to get something out of the agreement" (*Vereniging Afvalbedrijven*).

One of the over 200 Dutch Green Deals that has been completed since 2011, concerns residues from waste incineration. One of the main goals of this agreement is to reduce pollution levels in bottom ashes by 2020 to the extent that it can be used freely, without precautionary measures such as isolation (Lamers, 2015). If this is not reached on a voluntary basis, the 2020 target can become legally binding so that bottom ashes must reach the requirements for free use to be used as construction material what so ever (Lamers, 2015). In exchange, the authorities have "adjusted the limit value of one element, to facilitate the free use of bottom ashes" (*Vereniging Afvalbedrijven*).

Sludge

In Germany, a sludge certification system was developed following a decision by the German Government in the year 2002, the QLA (Quality Assurance System, 2007). This voluntary certification system included tougher requirements than the existing legislation, which increased credibility for using sewage sludge and the German "farmers were pretty happy with using sewage sludge." (*DPP*). As the limit values were sharpen with the implementation of the Fertilizer act in the year 2012, together with the upcoming ban on land application of sewage sludge through the Sewage sludge act in 2016, the certification system became redundant.

In the Netherlands there is also a Green deal (2016) for the recovery of phosphorus, primarily to promote struvite. This agreement has been multilateral, involving France, Belgian Flanders, the Netherlands and the UK with the aim of creating a European market for struvite by developing and harmonizing policies. Previously, there was no legislation for struvite, and "if there is no regulation there is no market" (*Isle*). Thus, in order to create a market for struvite, regulation was requested from stakeholders. At the same time, "industry agreed to create a pilot study" (*Nutrient Platform*) for the development of struvite recovery.

5.7. Acceptance and customer interest

Economically favorable conditions and technical qualifications can increase costumers' acceptance and interest in waste.

Ashes

The reason why the Danish Road Directorate is interested in ash as a construction material depends not only on a political target for bottom ashes, as the ashes proved to be "a technically sufficient material that holds together for a long time, at least on the same level as natural materials" (*Vejdirektoratet*). In practice, the local opportunities to access natural resources plays also a role, as it "becomes increasingly difficult to get permission to mine natural ballast materials, which increase prices" (*Vejdirektoratet*). However, the decisive reason for using ashes in road construction is that “they are attractive from the monetary point of view” (*BASt*), both for waste producers and potential customers.

The use of bottom ashes as a construction material in Denmark means that waste producers avoids landfilling with associated costs such as the landfill tax of around 80 € (Cewep, 2017). In Neatherlands, the deposition of bottom ashes is forbidden (Cewep, 2017). Given the high costs of landfilling, waste producers in Denmark can offer around 6-10 € per ton bottom ash for customers to receive it (Hedenstedt, 2015). For the contractor, the use of bottom ash brings revenues from the waste producer as well as avoiding costs for natural ballast material. Lower project costs ”saves also money for the road authority" (*Vereniging Afvalbedrijven*). At the same time ,”the costs of the contractor increases in terms of insulation and monitoring when using bottom ash in the road structure, which are compensated by the revenues from accepting the ashes " (*Vereniging Afvalbedrijven*).

Sludge

In Denmark, the sewage sludge are transported to the farmers either freely or with a payment, depending on the regional supply of manure. In the western parts of Denmark there is a “lot of livestock, which creates an excess of manure and is thus given away” (*Hede Denmark*). Since "manure is generally considered a higher quality fertilizer than sewage sludge" (*Isle*), waste water treatment plants must pay to create a market in regions where the presence of higher priority waste-based fertilizers is for free

The potential market for waste based phosphorus from phosphorus recovery is highly uncertain, not least since it shall be sold, rather than paid to get rid of. In addition, this phosphorus shall enter existing value chains for fertilizers. For recovery of phosphorus from ashes, the ash needs also to be sent to a recycler. Some researchers in Germany are uncertain if the fertilizer industry and the users (farmers) will be interested in waste-based fertilization, since the "existing system is adapted to primary fertilizers" (*KWB*). At the same time, farmers are less open to novelties, as "the importance of food safety increases" (*Nutrient Platform*).

6. HOW CAN THE CHALLENGES BE ADDRESSED?

This chapter discusses how the Swedish challenges can be addressed through the experience from Central Europe. Each sub-chapter begins with a brief summary of each challenge. Thereafter, different trajectories for waste policy are presented that can potentially address the challenges.

6.1. How can trust in the regulation increase?

Sweden's waste policy is too strict when it comes to the use of bottom ashes and too liberal for land application of sewage sludge.

- **Hazards in relation to masses or resources**

A comparison between the Swedish criteria for using sewage sludge in agriculture and waste in constructions, Table 14, demonstrates that the level of cadmium and mercury should be 25 % lower to cover a landfill than applied to arable fields. In addition, documentation and traceability are required when sludge is used as a construction material (SCS, 2013), but not when applied to agricultural land (SCS, 1998; Jordbruksverket, 2017b).

Table 14. Comparison of Swedish limits for applying sewage sludge to arable land and guiding values for applying waste to constructions or cover landfills.

Waste type	Sewage sludge	All Waste	All Waste
Use	Agriculture	Free use	Landfill cover
Cadmium (cd)	2	0,2	1,5
Copper (cu)	600	40	80
Mercury (Hg)	2,5	0,1	1,8
Lead (Pb)	100	20	200
Nickel (Ni)	50	35	70
Zinc (Zn)	800	120	250

A waste policy that allows higher levels of the "hazardous metals" (Kemikalieinspektionen, 2015) - mercury and cadmium - in waste that is applied to arable land than to a landfill top demonstrates shortcomings in the risk assessment. However, allowing higher levels of hazards in the sewage sludge applied to arable land may be rational. The value of resources such as phosphorus, nitrogen and humus-forming substances in the sludge may outweigh the risks of contamination. On the other hand, the resources in sewage sludge when it is used in structures - its shape and stability- have relatively lower value. This means that higher levels of contamination can be tolerable in waste used in agriculture then in constructions. But, in such a case, the level of hazards should not be expressed in total concentration of the total mass (mg/kg) but in relation to the presence of resources. Similar to the requirement for fossil fertilizers of maximum 100 grams of cadmium per kilogram of phosphorus (mg cd/kg

P)[1]. Likewise, the level of hazards in bottom ashes could be expressed in relation to its function, for example, the bearing capacity.

- **Leaching concentrations or total concentrations**

The use of waste as a construction material can be controlled by leaching concentrations and/or total concentrations. In Sweden, total concentrations are often "the limiting factor for using bottom ashes in constructions" (*Avfall Sverige*). In Flanders, total concentrations are guiding values, while the leaching concentrations are limit values (Flemish government, 2012) and are thus more controlling. The reason why leaching concentrations can be a better indicator of risk than total concentrations is that pollutants in waste exhibit lower mobility than in virgin materials, as they are often added actively to fill a function (Trafikverket, 2012). For example, ”copper do not move anywhere. It will move maximum 10 cm in the soil and remain close to the application” (*Danish Waste Solutions*). However, measuring total concentration will remain important as it indicates long-term risk.

The use of sewage sludge that is applied to arable lands is currently regulated solely on the basis of total concentrations (SCS, 1998), in difference to if the same waste would be used in constructions, where also the leaching concentrations would apply. Similar to the use of waste as a construction material, the leaching concentrations could also become a requirement for sewage sludge application. However, a disadvantage of relaying on leaching concentrations is that the leaching may be the outcome of temporary conditions and change over a day (Höllen, 2018; Avfall Sverige, 2017).

- **Differentiated conditions based on the material or context**

There are many different models that can be used to differentiate requirements for waste as a construction material (chapter 5.3). For example, based on the context of the use, with different limits for a parking lot or a day care (Finish Government, 2017), how the waste is covered (Rijkswaterstaat Water, 2007) or based on the properties of the waste and its ability to permeate water (Flemish government, 2012).

A differentiated model could also be interesting to apply to sewage sludge. For example, according to the Norwegian model, where cleaner sewage sludge is allowed to be used on fields, while more contaminated sludge can be used in parks and green areas (Miljøstyrelsen, 2018a). Today there are no limit values for using sewage sludge on green areas in Sweden

[1] EU (2016) has proposed stricter limits for cadmium content in mineral fertilizer, initially 60 mg Cd/kg, to be tightened to 40 mg Cd/kg after 3 years and to 20 mg Cd/kg after 12 years.

(Svenskt vatten, 2018a), and low flexibility for using waste in constructions (Naturvårdsverket, 2010).

However, in the Netherlands, several problems have been encountered in use of polluted waste in isolation (Figure 2). For example, the waste can fall below groundwater level, complicates the construction process, and requires continues monitoring (Lamers, 2015). The increased levels of heavy metals can also be forgotten over time when the site shall be transferred to another use

- **Limit values based on the risk or the waste**

Limits values for using waste in the society are generally formulated based on a risk assessment. A risk assessment typically presents low-risk levels of contaminations based on criteria that will, for example, protect human health and surface and groundwater (Naturvårdsverket, 2013; Saveyn et al., 2014).

Another way to formulate limit values is based on the characteristics of the waste. For example, the proposed waste legislation in Germany (Umwelbundesamt, 2017) has different limits for different wastes, "since they have partly abandoned the risk analysis to instead construct the limit values based on the specific waste, as to open up for the waste to be used as a construction material" (*Danish Waste Solutions*).

For sewage sludge, the Danish EPA thinks that the limits of hazards could become stricter, since the general levels in the sewage sludge have already decreased, “the Danish sewage sludge has a quality that makes stricter Danish limit values possible” (Miljøstyrelsen, 2018a). Hence, should the limits be based on the risk or the waste?

6.2. How can the security increase for future policies?

There is uncertainty about how the forthcoming policy for bottom ashes as well as for sewage sludge shall be formulated.

- **Bottom-up or top-down formulated policies**

Policies for using waste can either be formulated in an agreement between involved actors or formulated top down from authorities. Policies formulated voluntarily could, for example, be a certification system where stakeholders such as waste recipients and waste producers agree on the terms. However, the risk of voluntarily policies is that they can create a lock-in, where authorities feel that there is "a sufficient solution in place, so there is no reason to give the issue any attention" (*LRF 1*). Policies can also be formulated by the authorities through limit values or requirement. Top-down policies may, on the other hand, have a low market adaptation, and, for example, an "uncertain market for the waste in question” (*Isle*).

There are also combinations of top-down and bottom-up policies in the form of the Dutch model referred to as "Green Deals", where the authorities enter into partnership with societal stakeholders (Green Deal, 2015). The advantage of this type of agreement is that it gets close to the market, "the low hanging fruits are picked first" (*Isle*) compared to top-down formulated policies. For example, in the Netherlands, the focus through the Green Deal is on phosphorus recovery through struvite, which is already being done on a full scale. In Germany, on the other hand, the top-down formulated “requirements for sludge management steers towards phosphorus recovery from ash” (*Isle*), which has a high potential, but major uncertainties.

- **End of pipe or preventive solutions**

The solutions proposed to increase the use of waste and reduce contamination are either "end of pipe" or preventive solutions. End of pipe solutions address already generated pollution, by redirecting it away from humans and the environment. Preventive solutions aim at preventing the generation of the pollution at the source (Sarkis & Cordeiro, 2001). The policy for sewage sludge management in European countries shows a clear division of preferred choice. In many northern European countries, such as Denmark and Sweden, waste water treatment plants have tried to stop the pollutants upstream and prevent users to release pollutions into the sewer. However, in the German-speaking countries, Germany, Switzerland and Austria, preventive work has been or will be replaced by bans on application of sewage sludge to arable land and requirements for phosphorus recovery (ESPP, 2016; 2017; BMU, 2017). This brings a focus on the resource instead of the contaminants.

The use of "end of pipe" technology for extracting phosphorus reduces the problem of contaminations, which is difficult to reduce upstream, such as drug residues and micro plastics in the sewage sludge (Kabbe, 2015). The waste based fertilizer becomes thus cleaner, but at the same time there are risks of rebound effects. For example, phosphorus recovery and banning sludge "may reduce the incentives for working upstream for a cleaner sludge" (*Isle*), which may increase the levels of pollution in the residual sludge and possibly in the water that flows into the recipient. At the same time, most of the technologies for phosphorus recovery from ash are based on extraction through leaching (Kabbe, 2015). For example, in the Swedish project "Ash2Phos", the ash is firstly dissolved in hydrochloric acid, then is phosphorus precipitated in chemical processes (von Bahr, 2018), which means further addition of chemicals. Phosphorus recovery from ash risks thus of creating residues with in total higher pollution levels than before, although the residues will not be applied to fields.

Furthermore, extracting resources end of the pipe brings often a focus on an individual resource, just like conventional mining, where less valuable resources are excluded, ending up in landfills. Recovery of phosphorus from sewage sludge means that nitrogen and other nutrients in the sewage sludge are discarded. However, the potential climate benefit of recovering nitrogen from sludge is about 70 times greater than recover phosphorus (Jönsson, 2005). It is thus important to analyze different trajectories from a system perspective, both when it comes to toxicity and climate impact.

- **Incremental changes or social transitions**

The waste polices can have different relationships to the existing system. The solutions can either be a complement to the existing social-technical system, referred to an *incremental change* (Abernathy & Utterback, 1978), or require a radical transformation of the system, also called a *tranistion* (Elzen et al., 2004). End of pipe solutions are usually of incremental nature, since such solutions are implemented in the end of the existing system, without changing its infrastructure. Preventive solutions, on the other hand, can require major changes. For example, waste prevention is not about circulation of waste, but a questioning of the whole growth paradigm (Johansson & Corvellec, 2018).

However, in the policy discussion about sewage sludge management, the end of pipe solutions requires more changes of the system than the preventive solutions. The preventive work performed by waste water treatment plants does not affect the water and sewage system, since the focus is upstream, before the contaminants enter the system. On the other hand, phosphorus recovery means in a Swedish context either to replace chemical treatment methods with biological treatment for struvite crystallization, or that new waste incineration plants will be built to burn the sludge into ashes before phosphorus are extracted. This will require large investments (Nättorp et al., 2017) and bring changes to the current system.

Phosphorus recovery does, however, not affect the water and sewage infrastructure of pipes, since it is connected to the end of the sewage system. Others argue that a more sustainable alternative for the future is source separated infrastructure (Mcconville et al., 2017), where the sewage leaves the house in different pipes, similar to how the solid household waste is sorted into different flows. However, this proposal entails a total new water and sewage infrastructure, which has a value of € 68 billion (Svenskt Vatten, 2016), and therefore received attention merely as a possibility in new building projects.

In the case of bottom ashes, foremost incremental, end of pipe solutions have been discussed, to reduce the contamination levels, for example by washing (AEB, 2015) or fine sorting

(Johansson et al., 2016). Waste incinerators have worked preventive upstream, by controlling the inflow to the incineration plants through input criteria, primarily to reduce air pollution (Avfall Sverige, 2018c), which has also affected the quality of the bottom ashes. There are discussion about transforming the waste system (i.e. Alterås, 2017), for example, to increase recycling and decrease incineration of waste, but rarely driven from the ash perspective. Increased recycling and reduced waste incineration would, however, not only reduce carbon dioxide emissions but also the total amount of ash and its hazards.

- **Requirements according to capacity or risk**

The same waste policy applies normally to all stakeholders. However, in Germany the responsibility for realizing the sewage sludge policies falls on the major wastewater treatment plants (BMU, 2017). The requirements are thus differentiated depending on the operators' financial muscles. As waste problems become increasingly expensive, complex, and even *wicked* (Lach et al., 2005), requirements in relation to capacity or financial muscles could be an interesting way forward. The problem of differentiating requirements is that those with lower economic capacity need to accept higher levels of hazards. For example, the environment and humans living close to small waste water treatment plants in Germany may be exposed to continued application of sewage sludge to arable land.

6.3. How can the institutional capacity for waste as a resource increase?

The political conditions for using primary resources are more advantages than for using secondary resources. In addition, the requirements for the same material may geographically differ.

- **Centralized or decentralized authority.**

Criteria for using waste can either be decentralized where each region sets their own requirements or be centralized where the same rules apply across the country. In Germany, the criteria for using waste such as bottom ashes in constructions is decentralized to each region (ger: *Bundesländer)* (Umweltbundesamt, 2003.), while in Sweden, decisions are to be taken case by case, by the local authorities (SCS, 2013; Naturvårdsverket, 2010). As German regions are relatively large such as North Rhine-Westfalia, with more inhabitants than the total population of Sweden, they have developed their own regional requirements for using waste in constructions (Höllen, 2018). This has, however, created large policy differences in Germany. For example, in Brandenburg "bottom ashes are classified as hazardous waste as a rule" (ITAD), while bottom ashes are classified as non-hazardous waste in Hamburg, where it is used relatively extensively, for example, in driveways (Hedenstedt, 2015).

In Denmark (Miljøstyrelsen, 2016) the Netherlands (PVL, 1995) and Finland (Finish Governemnt, 2017), the requirements for using waste in constructions are the same throughout the country. The advantage of centralized regulation is that it becomes more predictable and legally solid. When criteria are permitted locally, there is always a risk of appellation, which might turn the construction illegal. The advantage of local decisions, on the other hand, is that the criteria can be adapted according to local conditions. However, small authorities lack generally the capacity to set independent criteria.

- **Differentiated or similar polices for primary and secondary resources**

Normally, the requirements for using waste are stricter than using the virgin counterpart (cf. Johansson et al., 2013). However, experiences from the Netherlands (PBL, 1995) and Germany (Umwelstbundesamt, 2012) demonstrate that it is possible to formulate shared policies for using waste based and primary resources. However, the same hazards can act differently in waste-based and primary materials (Trafikverket, 2012).

- **Institutional fragmentation or coherence**

The unbalanced requirements for primary and secondary resources can be understood as institutional differences. In most countries, responsibility for the virgin resources lies under the Ministry of Industry and their Geological Survey. In Sweden, the Geological survey has even an explicit mission to support virgin resource extraction (SCS, 2008). On the other hand, the responsibility for waste-based resources lies under the Ministry of Environment and its Environmental Protection Agency. The same division of primary and secondary resources could be found within the institutions of EU. This means that virgin resources become a business issue to be supported, while waste-based resources become an environmental issue to be controlled (Johansson et al., 2016; Johansson & Metzger, 2016).

When an agency, usually the geological survey, are commissioned a responsibility, for example, for ballast material (SGU, 2017), the specific resources under their responsibility are primarily in focus. In France, on the other hand, the French Geological Survey (BGRN) is responsible for both primary and secondary resources, which means, among other things, that they present both secondary and primary resources in resource inventories (BGRN, 2014).

- **Resource or waste oriented policies**

There could be tradeoffs for waste producing organizations between cleaning the flows as effective as possible in order to protect the environment, or acquire good quality residues for reusing. In Sweden, waste water treatment plants are constructed to remove effluents and prevent pollution from reaching the recipient (Svenskt vatten, 2018b). This means that the quality of the residues from the treatment process, in the form of sludge, becomes secondary, with low plant availability of the nutrients. On the other hand, wastewater treatment plants in the Netherlands seem to have a different organizational objective. Although the treatment of wastewater is a priority, some reduction in the treatment capacity is accepted since biological treatment methods has lower efficiency, but can produce phosphorus struvite.

A problem for waste producers in the Netherlands, who wants to produce resources have been that their organizational culture is by law adapted to protect the environment. Waste water treatment plants shall “not make profit” (*Nutrient platform*), in line with the purpose of protecting nature. But if waste shall “become a product, rather than discarded, they need to adopt a business mentality, think like business”(*Nutrient Platform*) in order to compete in the market with primary resources.

- **National or multilateral policy**

Waste polices are normally a national issue. But at the same time, waste, especially in the form of resources is traded on the international market, sometimes because of national legal differences. For example, bottom ashes are transported from Brussel to neighboring regions and countries with lower or other legal requirements (Hedenstedt, 2014).

Also for sewage sludge, the policies of one country will directly affect other countries, since the product produced from waste in one country could be traded in the global market A large proportion of the vegetables and food consumed in Sweden comes from countries, such as Denmark, Norway, Spain and France, with a high level of sewage sludge applied to agricultural land (Jordbruksverket, 2017a). This means that Sweden's consumers are directly affected by the waste policies of other countries, regardless of the decisions taken in Sweden. In Spain, the sewage sludge applied to arable soil are allowed to contain contamination levels that would be classified as seriously polluted soil in Sweden (Naturvårdsverket, 1999), Table 15.

Table 15. A comparison of limits for applying sewage sludge to arable land with Swedish criteria for contaminated areas.

Substance	Sweden	Denmark	France	Spain	Polluted	Seriously polluted
Cadmium (cd)	2	0,8	20	40	1,2-4	>4
Copper (cu)	600	1000	1000	1750	300-1000	>1000
Mercury (hg)	2,5	0,8	10	25	3-10	>10
Lead (pb)	100	120	800	1200	240-800	>800
Nickel (ni)	50	30	200	400	105-350	>350
Zinc (zn)	800	4000	3000	4000	1050-3500	>3500

References: Mininni et al, 2015; Naturvårdsverket, 1999

There are thus huge differences in the criteria for applying sludge to arable land, even though there is a common regulatory framework for sludge management in the EU (1986). However, such a shared regulatory framework within the EU is lacking for waste used as ballast material.

6.4. How can costumers' willingness increase?

Today, potential customers see few reasons to use waste-based materials instead of conventional virgin materials.

- Financial compensation or investment

In order for costumers to be interested in sewage sludge as well as bottom ashes, compensation is often required, especially where the access to other, higher quality secondary materials are plenty. In many cases, compensation may be required to cover the increased costs that come with the additional security requirements. At the same time, a payment means that less money can be invested upstream in reducing the risks of using the waste. In some cases, customers have therefore agreed to "instead of receiving financial compensation, the money has been invested in preventive work upstream to improve the quality [by lowering heavy metal levels]" (*HD Biorec*).

- Direct or indirect political governance

In all the countries studied, the state has created policies, for example, criteria for using waste in the society. In Denmark and the Netherlands, which has a comparatively high use of bottom ashes, the state has also entered the value chain and become an active party in the waste market by using the bottom ashes generated in the country as construction materials. In Sweden, however, the Road Administration do not see a reason to engage in substituting ballast materials to waste-based materials because the replacement of other virgin materials with higher climate impact is more prioritized (Trafikverket, 2017). However, if another objective would steer the environmental work of the Road Administration, such as *groundwater of good quality* (Miljömål, 2018), the importance of finding waste based alternatives to ballast materials could become a prioritized issue.

- **Waste as a hot topic or asleep**

Despite the same scientific understanding, waste issues in some regions seem to be political, widely discussed, while in other regions sleeping (see Hird et al., 2014), which affects the possibilities for using waste. In "Sweden and Denmark, the scientific understanding and knowledge of sludge application to arable land is largely the same" (*la Cour Jansen*). In addition, the quality of sewage sludge is at least as high in Sweden as in Denmark (see REVAQ, 2018; Mininni et al, 2015). The differences seem instead partly to derive from the debate climate. In "Denmark, the sewage sludge issue is not much debated" (*la Cour Jansen*), while there is "many dark headlines in Sweden" (*HD Biorec*). For example, the Swedish debate on micro plastic in sewage sludge led to "several farmers refusing to accept sewage sludge " (*HD Biorec*). The interest of the customer in using waste can thus depend partly on whether the issue is a “matter of concern” (Latour, 2004), such as in Sweden or Germany, where the negative impact of the sludge is discussed or if it is asleep as in Denmark where discussion is partially absent.

6.5. How can access to alternatives be handled?

It is difficult for waste producers to find an outlet for their masses, not least as competition increases from other waste-based materials.

- **A material or social challenge**

The transition to secondary resources can be driven by uncertain availability of resources in the Earth's crust, but in many cases the decisions appear to be political. For example, a reason given to why Denmark and the Netherlands have a high use of bottom ashes as construction materials is the shortage of natural ballast materials in the ground (e.g. Aggbusniess, 2011). However, the long-term resource availability of ballast materials, at least in the form of sand, in these countries seems extensive. For example, the Geological Survey of Denmark (2014) estimates that there is almost 100 billion tonnes of "sand, gravel and stone" left in the bedrock. The Geological Survey of Netherlands (2005) estimates that the amount of remaining aggregate resources in terms of coarse sand corresponds to "7500 times the current consumption level, and is virtually undeletable". Furthermore, the prices of natural aggregates are slightly higher in Sweden (9 €/tonne) than in the Netherlands, France and Germany (6-8 €/tonne) (EAA, 2017), probably due to longer transport distances.

Uncertainties about the availability of phosphorus in the Earth's crust have also been presented as a reason for promoting waste based phosphorus. In Germany, the demand for phosphorus recovery was argued “firstly with scarcity” (*KWB*) in connection to the discussions about “peak phosphorus” (Cordell & White, 2011). However, after new phosphorus reserves were identified, the estimations of the total P reserves increased four times (USGS, 2011). Subsequently, the argument for phosphorus recovery in Germany is since then that “Phosphorus rock is located in political instable countries" (*KWB*), and thus an insecure asset. However , "Germany receives 50% of its mineral fertilizers from *Eurochem*, a Russian company located in Switzerland with capital companies located in Cyprus, with Phosphorus rock origin from Russia" (*KWA*).

- **Alternatives: primary material or secondary material**

The consequence of policies may have different consequences depending on the country's bedrock. In Sweden, and Denmark, the use of sand and gravel as construction materials has decreased, partly due to tax on natural gravel (Naturvårdsverket, 2004). However, policies to reduce the use of natural gravel had different effect in the countries. In Denmark, secondary materials such as bottom ashes have replaced gravel and sand as ballast material. In Sweden, on the other hand, another virgin material in the form of crushed rock substituted gravel, since the Swedish bedrock, in difference to Denmark, consists of mountains. Using crushed rocks instead of natural gravel as a ballast material is positive for water purification, but leads to increased energy use and higher carbon dioxide emissions (Naturvårdsverket, 2004). Compared with secondary materials such as bottom ash, the use of crushed rock requires also mining operations with impacts on nature and local communities.

- **Same or different requirements for secondary materials**

The requirements for using different waste fertilizers differ in Sweden. For example, sewage sludge applied to fields requires, according to REVAQ (2018), that 60 different elements are controlled, while for digestate only 7 (Avfall Sverige, 2018b), and manure do not need to be tested, although a considerable amount of medicine (>10 tonnes) are used for Swedish livestock (Jordbruksverket, 2016). On the other hand, the requirements for using waste as construction material are the same regardless of material type in Sweden (Naturvårdsverket, 2012). However, the forthcoming waste legislation in Germany (Umweltbundesamt, 2017) will put different requirements for using different types of waste as construction material.

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APPENDIX I

Overview of leaching concentrations for using waste in constructions.

	Method (L/S)	Unit	Arsenic (As)	Cadmium (Cd)	Chrome (Cr)	Copper (Cu)	Mercury (Hg)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)	Use in roads
Sweden Unbounded	10 l/kg	mg/kg	0,09	0,02	1	0,8	0,01	0,2	0,4	4	< 5%
Sweden Landfill cover	10 l/kg	mg/kg	0,4	0,007	0,3	0,6	0,01	0,3	0,6	3	
Denmark Category 1	2 l/kg	mg/l	0,008	0,002	0,01	0,045	0,0001	0,01	0,01	0,1	100%
Denmark Category 2	2 l/kg	mg/l	0,008	0,002	0,01	0,045	0,0001	0,01	0,01	0,1	
Denmark Category 3	2 l/kg	mg/l	0,05	0,04	0,5	2,0	0,001	0,1	0,07	1,5	
Flanders Unbounded	10 l/kg	mg/kg	0,8	0,03	0,5	0,5	0,02	1,3	0,75	2,8	40 %
Flanders Bounded		mg/m^2	27	1,1	55	25	0,8	60	15	90	
Netherlands Unbounded	10 l/kg	mg/kg	0,9	0,04	0,63	0,9	0,02	2,3	0,44	4,5	100 %
Netherlands Bounded	E64d	mg/m^2	260	3,8	120	98	1,4	400	81	800	
Netherlands IBC-material	10 l/kg	mg/kg	2	0,06	7	10	0,08	8,3	2,1	14	
Germany Category 1	10 l/kg	mg/l	0,01	0,002	0,015	0,05	0,0002	0,02	0,04	0,1	25 %
Germany Category 2	10 l/kg	mg/l	0,04	0,005	0,075	0,15	0,001	0,1	0.15	0,3	
Germany Category 3	10 l/kg	mg/l	0,06	0,01	0,15	0,3	0,002	0,2	0,2	0,6	
Finland Road structure Covered	10 l/kg	mg/kg	1	0,04	2	10	0,03	0,5	2	15	?
Finland Road structure Coated	10 l/kg	mg/kg	2	0,06	10	10	0,03	2	2	15	
Finland Ground Covered*	10 l/kg	mg/kg	0,5	0,04	0,5	2	0,01	0,5	0,5	4	
Finland Ground Coated	10 l/kg	mg/kg	1,5	0,06	5	10	0,03	2	2	12	
Finland Industrial ground	10 l/kg	mg/kg	2	0,06	10	10	0,03	2	2	15	
Finland Road of ashes	10 l/kg	mg/kg	2	0,06	5	10	0,03	1	2		
Range			0,008-260	0,002-3,8	0,015-120	0,045-98	0,0001-1,4	0,01-400	0,01-81	0,1-800	

* In Finland, there is also another more liberal category for a thicker layer of waste used covered in the ground.

References: Naturvårdsverket, 2010; Miljøstyrelsen, 2016; Umveltbundesamt, 2003, Flemish Government, 2012; Rijkswaterstaat Water, 2007; Finish government, 2017;

APPENDIX II

Overview of limit values for application of sludge to arable land. (mg/kg TS)

	Cadmium (Cd)	Copper(Cu)	Mercury (Hg)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)	Use in Agriculture (2010)
EU 86/278	20-40	1000-1750	16-25	300-400	750-1200	2500-4000	37 %
Sweden	2	600	2,5	50	100	800	25%
Germany	1,5	900	1,0	80	150	4000	30%
Denmark	0,8	1000	0,8	30	120	4000	52%
Spain	40	1750	25	400	1200	4000	92%
France	20	1000	10	200	800	3000	74 %
Netherlands	1,25	75	0,75	30	100	300	0%
Flanders	6	375	5	50	300	900	10 % (Belgium)
Range	**0,8-40**	**75-1750**	**0,75-25**	**30-400**	**100-1200**	**300-4000**	

References: Mininni et al, 2015; UmWeltbundesamt, 2018