

Actors' perspectives on barriers to the use of sewage sludge in Sweden

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ABSTRACT

Land application of sewage sludge has long been subject to concern. Among the reasons for these concerns are, for example, the occurrence of odours and the risk of spreading heavy metals and pathogens, but also a negative perception regarding the use of sludge. In this paper, we focus on the actors' perceptions of sewage sludge use and investigate, through a series of interviews with key actors and stakeholders in the sewage sludge management chain, how technology, the regulatory framework or public perception may function as barriers to valuing sewage sludge as a resource. The uncertainty following outdated legislation and constantly changing policies are frequently mentioned as the main barriers to investment in new technologies, which, in the respondents' opinion, creates a deadlock within the sector with no clear path forward. Although all respondents act and argue with a focus on environment and circularity, their overall sludge management strategies, as well as the issues they focus on, differ. Our study indicates that Swedish sludge management is, to a large extent, siloed and there is a clear need for a more holistic approach that can help actors to target common issues.

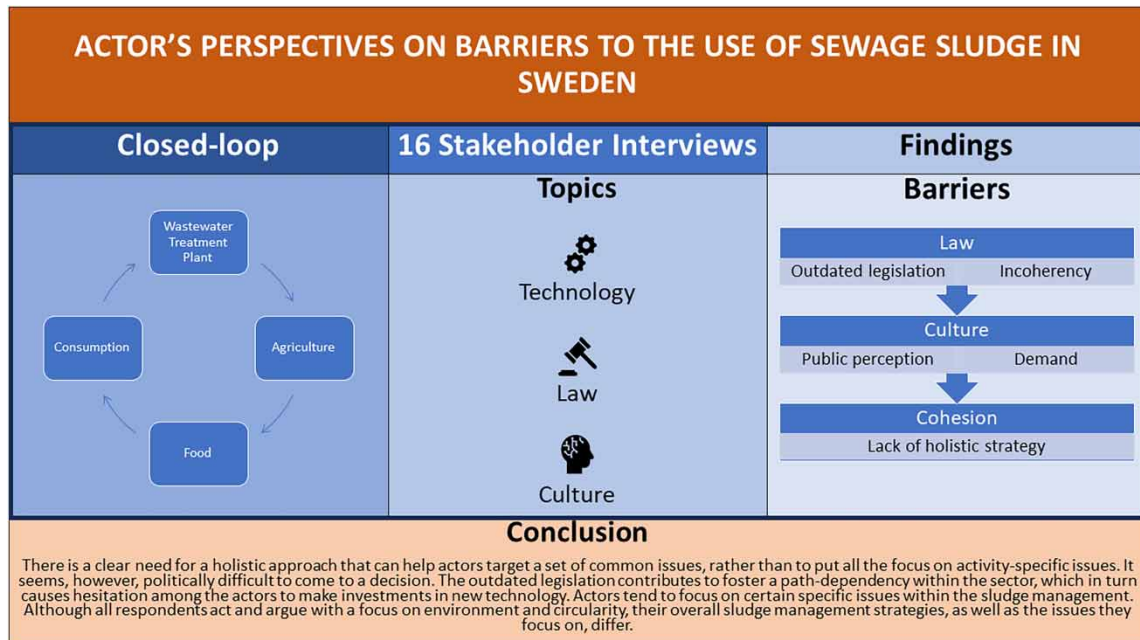
Key words: Circular economy, Environmental law, Fertilizer, Interviews, Waste-to-resource

HIGHLIGHTS

- Agricultural use of sewage sludge is a controversial topic.
- Through semi-structured interviews, the perception of stakeholders is investigated.
- The topic is currently in a vacuum with no clear path forward.
- Outdated legislation fosters uncertainty among the stakeholders.

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GRAPHICAL ABSTRACT



1. INTRODUCTION

Sewage sludge consists of the leftovers from wastewater treatment. The global amounts of produced sewage sludge are roughly between 25 and 45 Mt_{DS}/year (Bauer *et al.*, 2020). In Sweden, each person annually contributes to the production of about 20 kg of dry sewage sludge, resulting in roughly 200,000 t of dry sewage sludge being produced every year which rivals the amount of plastic packaging waste produced in Sweden (Statistics Sweden, 2020). As sewage sludge is normally handled with a dry matter content of 20–30%, the amounts handled are more in the range of 1,000,000 t per year in Sweden. Sewage sludge is a nutrient-rich waste that contains both valuables in the form of, for example, P and pollutants such as high levels of Cd or other heavy metals (Bauer *et al.*, 2020). This implies that there are constituents of sludge that could be utilized as a potential resource. A common method for recirculation of sewage sludge is land application of treated sludge as fertilizer (EUROSTAT, 2022), which can be argued to be an appropriate approach as the advent of a circular economy, together with *inter alia* the increasing fertilizer prices within the European Union (EU), calls for alternative ways of fertilizing the soil to be investigated. To recirculate waste as products is, however, not friction-free.

Following four main barriers to a circular economy are identified by Grafström & Aasma (2020):

- Institutional
- Economical
- Technical
- Cultural

In this paper, various actors' perceptions of sludge management and barriers for land application of sewage sludge is investigated through a series of interviews with key stakeholders and actors within Swedish sludge management. As far as the practice that is primarily investigated in this paper, the use of sludge as fertilizer on arable

land, land application of sewage sludge has in Sweden long been subject to concern, both by farmers and by the general public. Among the reasons for these concerns are, for example, the occurrence of odours and the risk of spreading heavy metals, pathogens, and organic contaminants, but also how sewage sludge is perceived, as the perception of risk heavily impacts the acceptance for (potentially) health and environmentally hazardous activities (Krogmann *et al.*, 2001; Whitehouse *et al.*, 2018; Robinson *et al.*, 2012).

There are several ways to dispose of sewage sludge; the main routes in Sweden being land application in agriculture (46%), soil production (23%), and usage in landfill covers (16%) (Statistics Sweden, 2020). While incineration of sewage sludge is a major disposal route in other European countries, only 2% of the sewage sludge is incinerated in Sweden, mostly by co-incineration in waste incinerators (Statistics Sweden, 2020; Eurostat, 2022). However, according to Lamastra *et al.*, land application of sewage sludge has the capacity to cover ‘the larger part of the nitrogen and phosphorus requirements for many crops’ (Lamastra *et al.*, 2018).

Empirical studies show that land application or recycling of sewage sludge are generally not favoured in the trade-off between costs (risks) and benefits. On a more general level, Kirchherr *et al.* examine stakeholder perception on circular economy barriers using a stakeholder survey. Out of four main barriers examined (cultural, market, regulatory, and technical) their research concludes that cultural aspects in the form of consumer behaviour are the most mentioned detriment by the respondents and technical being the fewest. The survey provides a helicopter perspective of the situation in the EU and does not distinguish between, for example, sectors, businesses, or countries (Kirchherr *et al.*, 2018).

Previous studies on the perception on land applications of sewage sludge include empirical studies in a North American context, both in the form of interviews (Krogmann *et al.*, 2001) and surveys (Whitehouse *et al.*, 2018). These studies confirm that public perception is a major concern and stress the importance of obtaining public acceptance, for example by ‘bringing the public into the decision-making process’ (Krogmann *et al.*, 2001:123). More recent studies show that males are more likely to perceive sludge use as positive than females (Nicholas *et al.*, 2022), and that in an Indian context, the concerns with using sewage sludge are focused on unpleasant odour, and fear of infection (Singh *et al.*, 2022). Regarding the use of sewage sludge as a resource, Rohrbach and Zimmermann employ a multi-level perspective to identify barriers and opportunities for the dissemination of technologies targeting such use. The study, which is based on the transition school literature (see e.g., Smith *et al.*, 2010; Smith & Raven, 2012; Pesch, 2015), uses six dimensions as a framework for investigating the room for improvement in the treatment and utilization of sewage sludge in China: industry structure, technologies and infrastructure, knowledge base, markets and dominant user practices, public policy and political power, and cultural significance. Twenty interviews with experts were conducted to gain a deeper understanding of the situation in China from the point of view of German companies and institutions. The result of the study confirms previously identified barriers and suggests ways forward to improve sewage sludge treatment and utilization in a Chinese context (Rohrbach & Zimmermann, 2023).

Interview studies targeting sewage sludge use have also been conducted in Sweden. In 2018, Nedelciu *et al.* interviewed 23 actors with the purpose of assessing to what extent global supply of phosphorous will be sufficient for regional fertilizer consumption given population growth, aiming to provide national level policy recommendations that can contribute to the development of phosphorous in the wastewater recycling sector (Nedelciu *et al.*, 2020). The study however only included respondents from Stockholm (and Budapest). During 2021, Ekane *et al.* did 17 interviews in the southern parts of Sweden with the aim of understanding ‘the underlying mechanisms on how different stakeholders see and explain the productive use of sewage sludge and associated risks (actual and potential), and the role these play in influencing their choices or decisions regarding sewage sludge and the purpose for which it should be used.’ They conclude that land application of sewage sludge is ‘an important way of recirculating nutrients and organic matter to grow crops’ (Ekane *et al.*, 2021:6). However,

the study also shows that the mere origin of sludge – i.e., not (just) its chemical characteristics – is marked by strong negative attitudes, including fear of contamination and feelings of disgust (ibid.). This is also confirmed by Ekman (2022), who describes sewage sludge as a multiple ontology in an interview study with experts in Swedish sewage sludge management. The study concludes that it is important to understand and acknowledge that the different usages, treatments, and opinions lead to different versions of sewage sludge, which will also exist if the sludge is treated differently in the future or if it is legislated differently (ibid.).

The present study adds to this knowledge by targeting how perceptions on sewage sludge impact the dissemination of technology and regulatory development. Thus, despite the presence of both regulation and, in some cases, voluntary certification schemes for wastewater treatment aiming to reduce levels of, for example, heavy metals, pathogens and drug residues in the ‘final product’, the differences of opinion regarding how the sludge can and should be used are wide-ranging.

To provide a necessary background to the interview responses, it is important to highlight identified shortcomings of the regulatory framework that governs sewage sludge management within the EU and by extension Sweden. Within the EU, sewage sludge is regulated primarily via three legislative acts: [The Waste Framework Directive \(2008/98/EG\)](#) which contains general rules applicable to all wastes (e.g., treatment in accordance with the waste hierarchy); the [Urban Wastewater Directive \(91/271/EEC\)](#) which contains specific rules regarding how residuals from wastewater treatment should be handled; and the [Sludge Directive \(86/278/EEC\)](#). The latter two pieces of legislation are considered as obsolete by representatives in the sewage sludge sector, including Swedish Water. Swedish Water for instance points out that the limit values in the Swedish legislation (SNFS, 1994:2), that is based on the sludge directive, allow for too high levels and emissions of heavy metals, have insufficient hygiene requirements, provide poor traceability, and include no mechanisms for upstream work (Pettersson & Johansson, 2022).

1.1. Aim and method

The overarching aim of the interview study was twofold:

- (a) To explore what drives the technological development of sewage sludge treatment and whether the actors perceive any barriers to the development and implementation of new sludge treatment technologies; and
- (b) To explore the adequacy of the legal framework; are the laws and regulations governing the use of sewage sludge clear and unambiguous, i.e., can they be applied or are there uncertainties about what is permitted/prohibited? Is the regulatory framework sufficiently complete or is there a lack of regulation around certain issues?

As the perception of risk derives from the values, beliefs, and experiences of the individual – which can also be shared by larger groups or communities – it is particularly important to investigate these matters empirically. In this study, qualitative data is gathered from 16¹ interviews with key Swedish sludge actors. The sample-size of 16 interviews can be considered to achieve saturation due to the homogenous nature of the respondents (Swedish sewage sludge management) and narrow scope of the study (Hennink & Kaiser, 2022). In addition, to create a dataset which represents the differences in Swedish sludge management, we have interviewed industry associations, researchers, authorities, municipalities² and companies. When selecting respondents, we considered their geographical location, their role in the sewage sludge chain, and their previous involvement in sewage

¹ Furthermore, we gathered input via e-mail from two authorities who did not want to participate in an oral interview.

² Municipalities include Wastewater Treatment Plants. Whether or not we interview the municipality or the WWTP depended on how the municipality had organized its wastewater treatment (i.e., through a municipality owned association or not).

sludge management. It was particularly important to get a diverse geographical spread of respondents as Sweden covers several climatic zones and geological environments, and in addition great variances in population density. This implies that both the amount of sludge produced, and feasible outlets available for treated sludge vary to a large degree depending on geographical location, which in turn implies that the opinions of the respondents may to a large degree be affected by their geographical area of operation. This also increases the novelty of the results as the previous Swedish research in this context has been limited to primarily southern Sweden.

Due to the uncertainties during and following the COVID-19 pandemic the interviews have been conducted online. Studies of this kind are not subject to prior ethical approval by the Swedish Ethical Review Board (Section 3 of Act (2003:460) on ethical review of research involving humans)³. Ethical deliberations were however made before conducting the study. The respondents were informed of the purpose of study and that the material would be used for scientific publications. As the Swedish sewage sludge management sector is relatively small and the issue of sewage sludge management has been subject to political discussions and conflicts, we have anonymized the participants to protect their identities as well as to give ample room for genuine answers (Saunders *et al.*, 2015). As the participants have been anonymized they have been assigned identifiers, for example, WWTP 1 or Government Authority 2 (see Table 2). The overarching aim was to explore how actors perceive both the technical advancements and the formal (regulatory) and informal frameworks for valuing sludge as a resource, including how land application is perceived in Sweden.

The interviews were semi-structured and followed an interview guide which contained broad, open-ended questions divided into three topics: technological barriers, formal⁴ institutional barriers and informal⁵ institutional barriers. Thus, the interview guide allowed for ample elaboration on the topics depending on the specific actor's role in the context (Whiting, 2008; Cridland *et al.*, 2015). Furthermore, semi-structured interviews allow for the respondents to focus on the issues they are knowledgeable about and meaningful for them. This flexibility is important not only due to the very different roles of the respondents but also because it facilitated spontaneous, in-depth and unique answers (Dearnley, 2005; Krauss *et al.*, 2009; Kallio *et al.*, 2016). The interviews all followed the same pattern of introductory questions followed by the three topics in order: technological barriers, formal barriers, and informal barriers. While all interviews were structured in this way, deviations occurred, both with respect to the order of the questions and regarding the questions posed following the different respondents' answers⁶. As all interviews were conducted in Swedish, all quotations are translated into English by the authors.

2. RESULTS AND DISCUSSION

An overview of the results of the study is presented in Table 1 followed by an in-depth presentation of the findings.

Regarding the overarching barriers to the utilization of sewage sludge as a resource, presented by Grafström & Aasma (2020), the key obstacle is the combination of obsolete legislation and poor economic conditions, rather than a lack of technological solutions. This is not surprising and aligns with previous research (Kirchherr *et al.*,

³ For a more thorough account see Swedish Ethical Review Authority (2021) <https://etikprovningmyndigheten.se/for-forskare/vad-sager-lagen/> [available in Swedish].

⁴ For the purposes of this study, we define formal barriers as i.e., direct or indirect barriers created by law. For instance, legislation which mandates too strict, or too lax, thresholds or the lack of legislation.

⁵ For the purposes of this study, we define informal barriers as i.e., direct or indirect barriers that fall outside of technological or the formal category. For instance, public perception which affects various outlets for sewage sludge.

⁶ It was common that a respondent would have already, directly or indirectly, answered a question in a reply to a previous question. This is a side-effect of open-ended questions.

Table 1 | Brief summary of the barriers and their consequences identified by the respondents.

Observation	Consequences
<i>Outdated legislation</i>	Lack of certainty, hinders investments, reduces legitimacy, untapped potential
<i>Discrepancies between wastes and non-wastes</i>	Waste-based products not competing on equal terms
<i>Lack of holistic strategy</i>	Path-dependency, current practice favoured
<i>Regional differences</i>	'One-size fits-all' solutions impractical

2018). Nevertheless, it implies that the challenges of introducing and developing new sustainable technological solutions are often a combination of, on the one hand, too lax requirements, and on the other hand, a lack of affordable technological solutions to achieve a requirement of, for instance, 60% P recovery from the sewage sludge. The latter is becoming increasingly difficult for smaller WWTPs and municipalities where 'enskilda anläggningar'⁷ are common and, due to long distance transportation, treat low quantities of sludge. The difficulties are further exacerbated by a lack of resources.

This is well illustrated by the different perspectives and goals from which the different respondents approach the sludge issue. All respondents mention the need for some form of change, from modest changes, such as updated legislation (all respondents), to more visionary proposals, including entirely reimagining the current wastewater practice where wastewater and sludge is primarily considered a resource rather than a waste. One respondent means that '[t]he treatment plants must become resource plants. We want legislation that supports the adaptation of treatment plants in that transition with a clearer message mandating that the nutrients must be returned [Consultant, Branch-organisation, Company 6]'. The responses are largely depending on where in the sludge management value chain the respondent is active. The current situation fulfils the criteria of a wicked problem⁸ where new technology is not being implemented rapidly enough, which could be addressed through stricter requirements, but where decision-makers and legislators do not seem to be able to decide on, for example, new policy or legislation. This is a critical point, and one of our respondents highlights that this situation creates a resignation of sorts: '[t]here are so many investigations and there are so many dead hands over the development so that we who are out in the business end up just sitting down and waiting for it to blow over [WWTP 1]'. This sentiment is essentially shared by all respondents, and in particular those who carry some degree of responsibility for the implementation of new technology. Overall, the respondents highlight several issues from both a legal and technical viewpoint, including obsolete legislation, outdated wastewater infrastructure and a lack of storage space.

2.1. Key finding: outdated legislation

Our study shows that a view that seems to be shared by both operators and authorities who are directly involved in day-to-day sludge management is that the WWTPs generally monitor more substances than what is required by legislation and also produce an overall cleaner sludge. One respondent stresses that 'we check the hygiene of the sludge even though we have no obligation to do so [WWTP 5]' and another says that 'all things considered, we have a good sludge that is below all current limit values [WWTP 1]'. This notion is confirmed by the authorities and one particularly illustrative quote is 'the limit values required by law are like twice as high, sometimes five times as high as the actual levels of the sludge and this is how it has been for many years, often improving

⁷ Swedish term for individual small wastewater treatment plants.

⁸ I.e., a policy related problem that is difficult, or even impossible, to solve as a result of incomplete, contradictory, and changing requirements.

with each passing year. [Government Authority 3]'. The same respondent continues to discuss how the levels of contaminants in the sewage sludge are reduced completely independent of the sector legislation (i.e., the sludge legislation) and is instead indirectly affected by other legislation such as REACH⁹ or the RoHS Directive¹⁰ or directly by voluntary certification schemes such as Revaq. Thus, 'best practice' is improving throughout the sector regardless of updated legislation or guidelines.

All respondents mention the lack of updated legislation as an issue (this is loosely paraphrased as all respondents do not use the exact word 'issue', but synonymous terms such as hindrance, problem, barrier etc.). However, from the point of view of the environment, it can be argued that the current system is effective as the treated sludge is in fact gradually becoming 'cleaner'. Although, it is not the legislated limit values that worries the stakeholders; they are easy to adhere to, but rather the uncertainty in what treatment methods will be allowed in the future. One respondent aptly describes it as: '[t]he lack of [legislation] and the concern over this is a huge problem and I would say is like a wet blanket over the whole industry [Government Authority 3]'. Thus, the opinion that the current legislation is outdated is directly or indirectly mentioned by all respondents. While some explicitly refer to the legislation as obsolete, others speak of the current treatment practices as resulting in a sludge which is much cleaner than the legislated thresholds mandate. Notably, there is no consensus among the respondents as to whether the current legislation promotes the utilization of sludge as a resource. The different opinions of the respondents regarding this are illustrated in [Table 2](#).

The different opinions can to a large extent be explained by where in the sewage sludge value chain the respondent is active. If the respondent is active in day-to-day wastewater treatment and works closely with the limit values these become the main factors to relate to, whereas respondents active in research, or respondents working at an authority, also have to relate to overarching goals and strategies for resource management. Notably, only three respondents are of the opinion that the legislation promotes the utilization of sewage sludge as a resource; one considers it as wholly promoting whereas two are more reserved stating that it depends on what level of legislation is addressed. For instance, it follows from the overarching purpose of the environmental legislation that there are clear indicators that resource recovery should be promoted, but sectoral legislation may cause undue barriers (e.g., limit values or abstract and ambiguous terms that are hard to interpret). This is nevertheless a prime example of law in actions versus law in books as the regulatory framework in theory provides ample opportunity to utilize treated sewage sludge as, for example, fertilizer. The limit values, as all respondents have noted, are very generous and easy to live up to. In relation to this it bears mentioning that the basis for the limit values within the EU is the Sludge Directive (86/278/EEC), which implies that the risk assessments underpinning the rules are based on the available facts in the mid 1980s. This likely contributes to the perception that the legislation counteracts utilization of sewage sludge as a resource as vastly out of date legislation carries with it reduced amounts of legitimacy. This conclusion is reinforced by several respondents and contributes to general unwillingness to accept the end product (crops).

2.2. Key finding: Coherent requirements between wastes and non-wastes

In relation to whether the legislation promotes or counteracts valorization of sewage sludge as a resource, the two most commonly mentioned shortcomings were outdated legislation (discussed above) and incoherency between wastes and non-waste. On the topic of whether sludge is or should be seen as a resource, some of the respondents

⁹ Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals.

¹⁰ Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Table 2 | Perceptions of the role of legislation for valuing sewage sludge as a resource.

Stakeholder	Response
Consultant, Branch-organisation, Company 1	Promotes
Consultant, Branch-organisation, Company 2	Counteracts
Consultant, Branch-organisation, Company 3	Neutral
Consultant, Branch-organisation, Company 4	Neutral
Consultant, Branch-organisation, Company 5	Counteracts
Consultant, Branch-organisation, Company 6	Counteracts
Government Authority 1	Neutral
Government Authority 2	Promotes and counteracts ^a
Government Authority 3	Promotes and counteracts ^a
Researcher 1	Counteracts
Researcher 2	Neutral
WWTP 1	Counteracts
WWTP 2	Counteracts
WWTP 3	Counteracts
WWTP 4	Neutral
WWTP 5	Neutral

Possible responses were the legislation promotes, counteracts or is neutral with regard to sewage sludge as a resource.

^aCertain parts of legislation promote; others counteract the use of sludge as a resource.

mention that the legislation controlling sludge utilization is to some extent incompatible with that idea. This is a recurring observation in relation to waste legislation in general. A clear example of this is that the current legislation is based on origin rather than on the quality of the sludge, which means that sludge-based fertilizers are subject to different requirements than other fertilizers, regardless of quality. As one respondent points out: '[t]he rules should be the same for all different [fertilizers] including artificial fertilizers, horse manure or whatever it is you put [on the arable land]. It should be regulated in the same way [WWTP 3]'. Diverging requirements depending on origin rather than quality suggests that the current legislation cannot be considered to promote best available practice. Different requirements depending on origin imply a lack of coherency between the regulation of waste and non-waste which has been identified as a key issue for the attainment of a circular economy in general (Friege *et al.*, 2019; Römph & Cramer, 2020; Alaranta & Turunen, 2021; Waal, 2021, 2023) and for fertilizers in particular (Štrubelj, 2022).

In relation to sewage sludge, this is illustrated by Regulation (EU) 2019/1009 regarding fertilizing products which entered into force in June 2022 and *inter alia* aims to harmonize the functioning of the inner market for fertilizers within the EU by facilitating utilization of secondary fertilizer (i.e., waste-based fertilizers). Although fertilizers (primarily fertilizers from mined, or chemically produced, inorganic material) were prior to this regulation harmonized through Regulation (EC) No 2003/2003 relating to fertilizers, the updated regulation confirms the need to utilize also other organic or recycled materials as fertilizers (Regulation (EU) 2019/1009 preamble 1). Sewage sludge is however principally excluded from most Component Material Categories¹¹ (CMC)

¹¹ CMCs define which input materials are allowed in EU fertilizer products.

(see e.g., Annex II articles 1(a); 3(c) and 5(c)). This is commented on in preamble 58 of the Regulation, where it is acknowledged that there are rapid technical developments concerning P recycling from sewage sludge and that, if necessary, the Regulation can be amended to include sludge-based fertilizers¹². Despite this reservation, the exclusion of sewage sludge on the basis of its origin, rather than its intrinsic qualities, strengthens the perceptions conveyed by our respondents. One respondent attributes this to a strong, ‘anthroposophist view’ in EU politics and expresses that ‘an anthroposophist has the opinion that what has passed through the human [body] is worthless, because the human appropriates what is valuable, and with that logic, the sludge would have no value and therefore it would not be interesting to circulate it [Consultant, Branch-organisation, Company 5]’. The aversion towards the use of sewage sludge as fertilizer is probably, at least to some extent, explained by such ‘anthroposophist views’. Not least in view of the strong tradition of using for example horse manure in agriculture. This is also in line with previous research showing that there is a strong stigma connected to the utilization of sewage sludge (Ekane *et al.*, 2021). It is nevertheless problematic as it may result in a legislation which prohibits spreading of less harmful substances while at the same time permits spreading of harmful substances merely due to their origin¹³. This is a critical issue that remains to be solved also for waste in general. While stricter requirements for waste-based products guarantee a certain level of environmental protection in the short term, they also, as repeated by our respondents, constitute a barrier for utilization of resources found in waste as they do not compete on equal terms with their virgin counterparts.

2.3. Key finding: triple regulating

In Sweden, the management of sewage sludge is also, in principle, subjected to a third regime: Revaq certification. In an effort to, among other things, alleviate the shortcomings due to the outdated legislation sector stakeholders and the Swedish Water association initiated the Revaq certification-system in 2008 (Pettersson & Johansson, 2022). The certification-system aims to enable trustworthy recycling of nutrients contained in sewage sludge and (hence) to increase public acceptance and thus the legitimacy of the end product. In short, the Revaq system essentially implies that sewage sludge that is to be utilized as a fertilizer is measured against three different yardsticks: non-waste legislation, waste legislation and the voluntary certification scheme.

One key component of the Revaq system is to create stricter environmental and health requirements for treated sewage sludge than what is required by the allegedly outdated legislation, as one respondent puts it: ‘the quality requirements for sludge are unfortunately, one might say, not driven by legislation which is hopelessly out of date’, and continues ‘the legislation is old and by being so old I think it undermines public confidence in sludge [Consultant, Branch-organisation, Company 5]’. The certification scheme sets stricter requirements and thus creates a different category of sludge that is cleaner and much more accepted by public and sector stakeholders for use in agriculture. On the other hand, the certification is costly and, according to one respondent, does not necessarily result in a sludge that is of higher quality than non-Revaq-certified sludge: ‘[WWTPs] advertise that their sludge is cleaner just because it is Revaq certified and that is utter bullshit because it is clear [that] it is not if you look at the content [of the sludge] [WWTP 4]’. This implies that while the certification-system is a much-needed tool to improve overall sludge quality it can also lead to problems as WWTPs can safeguard themselves from critique merely because they are certified. The general perspective is that if you are Revaq certified you produce a safe and clean sludge and if you are not Revaq certified you produce an unclean sludge. According to one of the respondents from a supervisory authority, however, the fact that Revaq certified WWTPs are generally located in densely

¹² As of the inclusion of CMC 13 sewage sludge is now allowed as an input if it has been treated via thermal oxidation. It is however still largely excluded as an input material, regardless of the quality of the end product.

¹³ This view is also reoccurring in the latest Swedish government inquiry on sewage sludge management within Sweden (SOU, 2020:3).

populated urban areas, means that the wastewater they treat is more polluted from onset, whereas non-Revaq-certified WWTPs are typically located in less densely or sparsely populated areas where the incoming wastewater is less polluted, thus resulting in a cleaner sludge, despite the fact that they are not certified. Several WWTPs, especially smaller ones, cannot afford membership in Revaq due to membership fees and expensive and time-intensive upstream work. As the certified sludge mainly has an economic advantage when it is used in agriculture, regions that have other outlets than agricultural use do not see the necessity of certifying their sludge, something that is particularly true for the northern parts of Sweden. On the other hand, given that Revaq not only mandates cleaner sludge but also includes proactive upstream work in the form of, for example, annually compiling lists of possible sources of selected priority trace elements or through an action plan improving the use and handling of chemicals by households and other connected businesses, this is unfortunate (Revaq, 2023). The importance of an extensive upstream work is highlighted by several respondents as a key component and benefit of the Revaq system. However, it is also important to note that currently emerging organic contaminants like PFAS are not included in the Revaq requirements in the form of limit values in the sludge, but only through upstream work for connected industry (Revaq Årsrapport, 2021; Revaq Regler, 2024).

2.4. Key finding: regional differences

An essential factor in the context of the application of the law, i.e., the role of law in practice, is the role of the decision-makers. In the most recent government inquiry on sludge management (SOU, 2020:3) it was suggested that the Swedish Environmental Protection Agency (SEPA) should have an increased responsibility and a coordinating role in the sludge management sector. Some respondents are however very critical of any influence given to the SEPA in fear of creating a top-heavy system with little actor influence.

No interviews with SEPA have been conducted within the framework of this study¹⁴. However, in e-mail correspondence SEPA describe the sludge issue as currently being in a vacuum, characterized by a lot of uncertainty, which is why the authority is reluctant to speculate on the issue. It is clear from our interviews that SEPA currently does not have great influence over the sludge treatment sector (this can be compared to the waste-sector in general where SEPA guidelines and guidance is ample). On the regional level, the knowledge and investments in sewage sludge management differ significantly between different County Administrative Boards (CABs). While all CABs are responsible for monitoring both wastewater treatment plants and their sludge management, the degree to which they are involved in these matters varies significantly. At some CABs there is a strong cooperation with WWTPs to improve sludge management and find sustainable solutions, whereas others, particularly in less populated regions, are not that specialized¹⁵.

The difference in engagement at the different CABs is not surprising given that different amounts of sludge are produced in different regions. If only a small amount of sludge is produced within the region, the need to find an outlet for the sludge is less, and hence there is a lesser need for a proactive CAB. As there are currently no general requirements on sludge quality, unless used in agriculture, CABs that do not oversee agricultural use are naturally less engaged in the issue. This nevertheless implies that the degree to which authorities (excluding municipalities) contribute to develop sludge management practices depend on administrative location. One respondent means that 'in general, neither the review authority nor the supervisory authority is overly interested in regulating [...] the use of sludge [WWTP 4]'. The quote specifically relates to the regulation of the utilization, rather than the

¹⁴ We tried to schedule interviews with representatives at SEPA, but they declined with reference to their 10-year-old study from 2013 where they investigated recovery of P from sewage sludge.

¹⁵ One CAB replied to our request for an interview with an e-mail saying that they are not dealing with sewage sludge management issues to a high degree (if) at all.

treatment, of the sewage sludge. In part, this can probably be explained by lack of time and resources at the authorities where one respondent states: '[t]he way I perceive the situation of the [CABs] at the moment, is that there are certain parts of the legislation where they should [...] function as a supervisory authority, but they do not have time to do that [...] [t]here is too much to do for them [the CAB] in relation to how many people they have [Researcher 1]'. The perception on how the CABs handle the issue in practice is also diverging and one respondent states, when asked if there is any uncertainty regarding what is allowed, that:

'Not when it comes to spreading sludge on arable land. But, different supervisory authorities have really strange things going on in my opinion. Where you are used to manure spreading, it does not have to be sewage sludge, like on Skåneslätten, there are no major obstacles. But if you try to spread the sludge elsewhere, e.g., in the Gothenburg region, then there will be problems with e.g., what precautions to take. It is, as I see it, not at the legislative level that the problems exist, but more how it is handled at the authority [WWTP 4].'

This implies that it is partially a problem of applying the legislation as opposed to a problem with the content of the legislation, and one respondent goes so far as to claim that it is possible to make more stringent demands within the existing framework that would foster recirculation of resources to a higher degree:

'National authorities, SEPA, CABs and municipalities in cases where they make demands on [activities due to] environment or health, [...] have continued as if it were 1996. [...] [w]e don't need to change any legislation [...] there could be guidance [...] regarding the cycle principle for how to set requirements for major environmentally hazardous activities and [...] how to apply chapter 2 section 5 of the Environmental Code tomorrow [Consultant, Branch-organisation, Company 3].'

The lack of resources at Swedish authorities is a recurring theme also within Swedish media, not least when it comes to innovative, resource intensive and potentially environmentally hazardous industries (Arbetsgivarverket, 2020). It is thus not surprising to see that this opinion is mirrored in our results.

It is not only the authorities' involvement that reflects the strong regional differences in the field of sewage sludge management, but also that of the actors. As Sweden is a country with large differences in population density as well as in the availability of arable farmland, both sewage sludge production and utilization in agriculture differ considerably between regions. This is particularly important as it implies that most 'one-size-fits-all' solutions will fail to properly account for regional differences. In addition, there are differences in the public acceptance of sludge utilization in agriculture within the country. Whereas the region of Västra Götaland faces protests against land applications of sewage sludge, there are far fewer controversies surrounding this in the east and south. According to some respondents, this has a historical background, while others mean that more public acceptance is partly a result of an ongoing dialogue with the public and other involved actors; a dialogue which was proactively established to gain public acceptance.

2.5. What is the path forward?

While several issues highlighted above are seen as potential issues within sludge management in Sweden by our respondents, the sludge is still as a rule becoming cleaner. One respondent [Government Authority 3] attributes this to the culture within the Swedish sewage sector and that there is an inherent driver amongst the employees at the WWTPs to produce the best possible product (i.e., clean water *and* clean sludge).

What then is the path forward? All respondents agree that the current legislation must be updated. However, they also frequently mention other, more short-term, issues, including storage capacity, gaining permits,

contradicting rules in different parts of the environmental legislation, lack of feasible outlets for treated sludge, or varying degrees of lacking public acceptance. The respondents also do not agree on what is the best path forward, that is, if spreading sludge on arable land as fertilizer is the best solution. Depending on the outlets the WWTPs have for their sewage sludge, the opinion largely differs between the respondents. This may be considered rational as some regions in Sweden simply (1) do not have enough agriculture to support sewage sludge spreading and (2) do have enough agriculture but access to other fertilizers such as stable manure.

This implies that while the respondents show a consensus regarding the need to change current practice that mainly focuses on end of pipe solutions, there is no consensus on what the solution is. While the quality of the sewage sludge is, as highlighted by our respondents, affected by common requirements for upstream work following, for example, the REACH Regulation, the different actors are still to a degree operating within isolated silos, or bubbles. This is probably a contributing factor to the lack of a clear vision on how sewage sludge should be managed in the future. Many respondents mention the lack of a holistic strategy for sewage sludge management as a barrier for branch developments. Some mention that the current system fosters both an institutional path-dependency and technological lock-in effects where current practice is favoured over new and innovative ideas.

3. CONCLUSIONS

Is there a silver bullet for the future of sewage sludge management? The results of this study indicate that the answer is no. A combination of different barriers – technical, economic, and legal – as well as obstacles related to public acceptance, create a substantial uncertainty that prevents development, both in the form of long-term sustainable strategies and technical advancements. While this qualitative study is limited to Swedish sewage sludge management, many of our identified issues are mirrored by previous studies (e.g., [Mininni *et al.*, 2015](#); [Kirchherr *et al.*, 2018](#); [Štrubelj, 2022](#); [Rohrbach & Zimmermann, 2023](#)) which increases the generalizability of both the previous studies and this study.

The Swedish sewage sludge management is, to a large extent, siloed and there is clearly a need for a more holistic approach that can support actors to target a set of common issues, rather than focusing almost exclusively on activity-specific issues. New, or at least updated legislation, could be one way forward here. As it currently stands, sewage sludge quality and -use in Sweden appears to be more affected by other legislation, such as the REACH Regulation and the Revaq certification scheme, than by the sector specific legislation on sewage sludge, which plays a seemingly insignificant role in today's sludge management.

The study also shows that the environmental legislation overall is not coherent. For instance, legislation on agriculture does not align with the sludge legislation (e.g., different phosphor allowances dependent on origin rather than quality). The interviews specifically point to the uncertainty following the outdated legislation and the constantly changing policies as the main barriers to investment in new technologies, which, in their opinion, creates a deadlock with no clear path forward. The issue has been subject to four Public Investigations by the State, and the current government is the fourth in line which has received a completed investigation. As of writing, it remains to be seen if any of the suggestions will be transposed through legislation as the investigation is (still) being processed at the Government Offices. In this situation, where it seems politically difficult to agree on a way forward, the outdated legislation contributes to foster a path-dependency within the sector, which in turn causes hesitation among the actors to make investments in new technology.

To conclude, actors tend to focus on certain specific issues within the sewage sludge management. Although all respondents act and argue for a focus on environment and circularity, their overall sewage sludge management strategies, as well as the issues they focus on, differ. This is a critical issue that needs to be addressed at the EU and national level as the current regulatory framework cannot be considered to foster organic change in the sector.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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