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Resources and Risks: Perceptions on the Application of Sewage Sludge on Agricultural Land in Sweden, a Case Study

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To spread or not to spread sewage sludge on agricultural land in Sweden remains the subject of a highly polarized debate among different stakeholders in the Swedish agricultural sector. This article presents insights on how stakeholders in Sweden see and explain the potentials and safety of spreading sewage sludge on agricultural land. This is done by drawing on risk perception literature and qualitative research methods. The findings reveal that fear of contamination and feeling of disgust are major deterrents of the use of sludge as an agricultural input. These are partly explained by unknowns and unfamiliarity about risks of unwanted substances in sludge. The study shows that while actors engaged in the practice amplify benefits of sludge as a resource and reiterate the need for emphasis on upstream measures including improved risk management systems, actors in charge of controlling toxins in society amplify actual and potential risks, highlight gaps in monitoring and minimizing risks, and would rather have a complete ban on the practice. This study highlights the complex combination of technical, environmental, socio-economic, psychological, and political factors influencing judgment and decision-making regarding sludge and its use as fertilizer in agriculture and concludes that the clash between facts and feelings which epitomizes the Swedish sludge debate may have implications for public trust and effective risk communication. As contribution to the Swedish sewage sludge debate, this study emphasizes that the benefits of sludge in agriculture is important but not enough to drive the practice to scale. It is even more important to improve understanding on the controllability and severity of risks in short and long-term.

Keywords: sewage sludge, agriculture, resources, risk, perception, stakeholders, non-toxic, circular economy

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INTRODUCTION

Over 200,000 tons of sewage sludge[1] are produced in Sweden each year, a large proportion of which is used for topsoil production and covering landfills (SOU, 2020:3). Only about a third (34%) of sewage sludge is spread on farmland annually as agricultural input (Statistiska centralbyrån, 2016; SOU, 2020:3). From a resource point of view, sewage sludge contains nutrients such as phosphorus (P),

[1]Mixture of solids and liquids, containing mostly excreta and water, in combination with sand, grit, metals, trash, and/or various chemical compounds. Originates from sewer-based wastewater collection and (semi-) centralized treatment processes.

nitrogen (N), potassium (K), and carbon (C) which are critical elements for plant growth (Herring and Fantel, 1993; Cordell et al., 2009; Rosemarin et al., 2009; Hudcova et al., 2019; Powers et al., 2019; Withers, 2019). However, from a risk point of view, sewage sludge also contains undesirable substances such as heavy metals (Cd, Cu, Hg, Ni, Pb, Zn), non-degradable microplastics[2], pathogens, antibiotics, and other antimicrobial substances, emerging groups of chemical substances such as per and polyfluorinated hydrocarbons or PFAS[3] and substances of concern which can potentially cause harm to human and environmental health if not properly or safely managed (Rockefeller, 1998; Buck et al., 2011; KSLA, 2013; Posner et al., 2013; Tóth et al., 2016; SAM, 2018; Hudcova et al., 2019; EFSA CONTAM Panel et al., 2020; European Food Safety Authority (EFSA), 2020). Even valuable nutrients such as P pollute aquatic and terrestrial ecosystems when applied in excess or indiscriminately to agricultural land through chemical fertilizers, sewage sludge, and animal manure (Kleinman et al., 2015; Barreau et al., 2018; Bol et al., 2018; Smits and Woltjer, 2018; Powers et al., 2019).

Uncertainties and unknowns regarding the nature, characteristics, fate, and impact of undesirable substances in sewage sludge make the handling and use of sewage sludge in agriculture in particular a complex and risky practice from a health and business point of view (KSLA, 2013; Statistiska centralbyrån, 2017; Gies et al., 2018; Hale, 2018; SAM, 2018; Hudcova et al., 2019; Pedersen et al., 2019; SOU, 2020:3). These uncertainties and unknowns have implications for societal perceptions and decision-making concerning the fate of sewage sludge, including the purpose for which it is to be used (Barreau et al., 2018; SOU, 2020:3). Unlike the productive use of sewage sludge in agriculture, topsoil production, and covering landfills with sewage sludge are generally acceptable practices despite the potential risks these practices may have on the environment (SOU, 2020:3). Even the application of other resources such as cattle manure and pig slurry on agricultural land is relatively more acceptable, even though these substances have been shown to also pose risks to human and environmental health (Pell, 1997; Köpke et al., 2007; Polprasert, 2007; Zhang, 2011; Dufour et al., 2012; Ekane et al., 2016; Pedersen et al., 2019).

Generally, the spreading of sewage sludge on agricultural land especially for food crop production faces resistance and remains a subject of a highly polarized debate among different stakeholders in the agricultural sector in Sweden (Wallenberg and Eksvärd, 2018; SOU, 2020:3)[4]. A ban on this practice is being considered and was part of the terms of reference (TOR) of the latest inquiry commissioned by the Swedish government. The purpose of this inquiry is to make proposals on how a ban on different uses of sewage sludge including the spreading of sewage sludge on agricultural land should be formulated and explore innovative technologies and strategies to extract or recycle P in sewage sludge[5].

This article examines perceptions on the potentials and safety of spreading sewage sludge on agricultural land in Sweden, and the potential economic, environmental, and social implications for the Swedish agricultural sector and society in general in case different options for managing sewage sludge are taken, including a complete ban on the spread of sewage sludge on farmland. The following research questions guide this study: How do different stakeholders understand and explain the use of sewage sludge in agriculture? What are the drivers and deterrents of spreading sewage sludge on agricultural land? To what extent are farmers dependent on sewage sludge as a viable agricultural input? What are the appropriate future options for dealing with sewage sludge with resource and risk considerations and the implications thereof for human and environmental health, economy, and technology development and innovation? The research questions are addressed through the collection of primary qualitative data from key stakeholders in the Uppsala and Stockholm regions. Specific emphasis was placed on the Uppsala region which is one of the case study regions in the Bonus Return project of which this study is part of[6]. Consumer perceptions were not collected and, therefore, are not discussed in this article.

From an applied behavioral sciences standpoint (Kahneman, 2013; Shafir, 2013), this study contributes with insights on the mechanisms underlying perceptions, judgments, and decision-making regarding the use of sewage sludge in agriculture. The first part of the article introduces Sweden's approach in handling sewage sludge in line with the national environmental objectives and presents recent developments in waste management with emphasis on harnessing nutrients from sewage sludge and curbing associated risks of this practice through innovative measures and quality standards. The arguments that characterize the debate between proponents or advocates and opponents or skeptics of the use of sewage sludge in agriculture are also introduced in this section. The second part discusses the theoretical background that informs the technological, psychological, and social processes and perceptions that drive and deter the use of sewage sludge in agriculture. The third part outlines the methodological approach in designing the study and collecting data. The fourth part presents and discusses the results from the empirical investigation with specific emphasis on key arguments of stakeholders at different levels in the agricultural sector, for and against the practice of spreading sludge on farmland. This is done with reference to trends that have shaped much of the thinking and interpretation on sewage sludge management in general and perceptions of the use of sewage sludge as an agricultural input in particular. Implications for future policy and regulatory design with respect to risk

[2]Solid plastic particles that are smaller than 5 mm in any dimension and insoluble in water (Kemikalieinspektionen).

[3]Perfluoroalkyl and Polyfluoroalkyl Substances—Large and complex group of organic substances that are extremely versatile and used in a variety of industrial and household applications (Posner et al., 2013).

[4]A series of recent debate articles on this subject matter in the Svenska Dagbladet (SvD) newspaper illustrate the polarity of the sewage sludge debate in Sweden.

[5]Kommittédirektiv 2018:67—Giftfri och cirkulär återföring av fosfor från avloppsslam.

[6]The objective of the Bonus Return project is to improve the adaptation and adoption of nutrient and carbon capture and reuse eco-technologies in the Baltic Sea Region for maximum efficiency and increased co-benefits www.bonusreturn.eu.

TABLE 1 | Recommended options for future sewage sludge management in Sweden (Extract from the on-going inquiry, SOU, 2020:3).

Option 1: Complete ban with very few exceptions	Option 2: Ban on the condition that possible risks are to be managed
• Follows the terms of reference of the inquiry. • Less realistic. • Large-scale technical solutions, principally the incineration of sewage sludge with extraction of P from ash. • Compromises opportunities for biogas production.	• Precautionary principle takes precedence. • Broadened and tightened requirements than at present for quality and sanitization of sewage sludge before spreading on farmland. • Allows the recirculation of not only P but also other nutrients like N and C.

management and communication, including limitations of the study are highlighted in the last part of the article.

One of Sweden's 16 environmental quality objectives is to create and maintain a non-toxic environment ("Giftfri miljö"). A key measure to achieve this goal is to restrict toxic substances that get into communities and remove and/or reduce fractions that are carried in wastewater streams and subsequently in sewage sludge (Naturvårdsverket Rapport 6580, 2013; Statistiska centralbyrån, 2017, 2018). In line with this goal, the Swedish Government commissioned a number of inquiries over the years (2010, 2013, and 2018) (Naturvårdsverket Rapport 6580, 2013; SOU, 2020:3) to explore possibilities of preventing undesirable substances in sewage sludge from entering terrestrial and aquatic ecosystems. Two options have been elaborated as part of the recommendations from the latest inquiry. Option 1 is a complete ban on the spreading of sewage sludge on farmland with very limited exceptions. Option 2 is a ban on the spreading of sewage sludge on the condition that possible risks are managed. The latter option involves stricter measures imposed on the practice with the requirement that at least 60% of P in sewage sludge is recovered and the associated risks are sufficiently managed. How the recovered P is to be used, in what form, and the type of system to govern this process was, however, not requested in the terms of reference of the inquiry (SOU, 2020:3). The key considerations for both options are summarized in **Table 1**. The need to recover other equally important nutrients such as N, K, and even C from sewage sludge is emphasized in the recommendations of this inquiry. This consideration was, however, not explicit in the initial terms of reference of the inquiry which constituted a major limitation of the scope of the task. Further, compliance has been raised by the Federation of Swedish Farmers or Lantbrukarnas Riksförbund (LRF) as a pertinent concern should a ban on sewage sludge be instituted. LRF warns that in the absence of a monitoring system including requirements on municipalities to report on the fate of sewage sludge, a ban on the practice may encourage "black" or illegal spreading on agricultural land.

Emphasis on P recovery is largely driven by the fact that point and non-point source P pollution have contributed considerably to P overload in major aquatic ecosystems (eutrophication potentials). This is, undoubtedly, a general concern for which there is consensus that the problem must be addressed (Naturvårdsverket Rapport 6580, 2013; Statistiska centralbyrån, 2017, 2018; SOU, 2020:3). However, the contention is whether sewage sludge is safe enough to be used as a source of recycled P on agricultural land for food crop production in particular. This is at the core of the ongoing Swedish debate on the benefits and risks of spreading sewage sludge on agricultural land (Wallenberg and Eksvärd, 2018; SOU, 2020:3). Proponents of the use of sewage sludge as an agricultural input make plausible arguments and encourage the practice as a viable and environment-friendly way of recirculating nutrients (Andersson, 2015; Wallenberg and Eksvärd, 2018). On the other hand, opponents or skeptics of this practice raise pertinent concerns regarding risks, knowledge gaps, trust with respect to origins and quality standards of sewage sludge, safety of the practice, and reputation of their business (Wallenberg and Eksvärd, 2018). Wallenberg and Eksvärd (2018) show from a survey of about 1,000 farms in Sweden that farmers are largely against the spreading of sewage sludge on their land. This resistance to the use of sewage sludge is the same for some major stakeholders in the food industry (Livsmedelsindustrin), particularly the dairy industry (Wallenberg and Eksvärd, 2018).

The sewage sludge debate in Sweden persists in the absence of a clear stance on the way forward on the part of the government and an updated national regulatory framework for sewage sludge management. The current national regulatory framework dates as far back as 1990 (SNFS, 1994, p. 2; Wallenberg and Eksvärd, 2018; SOU, 2020:3). Moreover, the government is yet to take forward policy and legislative recommendations from previous inquiries that were commissioned (SOU, 2020:3). Nonetheless, in line with Sweden's non-toxic environmental objectives, voluntary measures are being taken by a network consisting of a number of centralized wastewater treatment plants (WWTPs), some research and development organizations, actors in the industrial sector, and increasing numbers of municipal authorities to curb undesirable substances, notably heavy metals and microorganisms in sewage sludge. One of the major outcomes of these actions since 2008 is the voluntary Swedish REVAQ-certification system which puts requirements on over 39 centralized WWTPs with respect to treatment processes and quality standards for heavy metal and microbial content in sewage sludge. This quality control system emphasizes source separation ("upstream" work)[7] to reduce the quantity of undesirable substances entering wastewater streams and is based on trust and confidence between stakeholders (Persson et al., 2015; REVAQ, 2018). Some actors in the food retail industry such as Lantmännen accept agricultural produce fertilized with sewage sludge to be used for energy, export, and feed on the condition that the sewage sludge used by farmers is REVAQ-certified. Svenskt sigill does not accept any sewage sludge, but SPCR 178 certified products are allowed for some crops (Wallenberg and Eksvärd, 2018). The REVAQ-certification system is one of its kind in the European Union (EU) and puts Sweden at the forefront of innovations that markedly reduce heavy metal and microbial content in sewage sludge, notably Cd and salmonella, respectively. A similar voluntary certification

[7]Points in production that originate early on in the processes of wastewater production e.g. in households, factories, etc.

TABLE 2 | REVAQ and SPCR 178 certification.

REVAQ-certification of sewage sludge	SPCR 178-certified Biofertilizer
- Initiated in 2008 by Svenskt Vatten in collaboration with LRF, Livsmedelsföretagen and in cooperation with Naturvårdsverket for off-site solutions with quality of sludge in focus. Cd levels in sludge and other priority elements, tracability, transparency, and salmonella were major concerns. - Voluntary control system on what goes into the sewage stream and what is discharged from treatment plants. - Put strict demands regarding phasing out hazardous chemicals used on all industries connected to WWTP. - Involves mapping the source of different pollutants mainly heavy metals used at household and industrial levels and determining what is products should be avoided (Upstream work or source control). In some campaigns this is done in close contact with Naturvårdsverket and Kemikalieinspektionen. - Farm land fertilized with sludge are openly presented and there is a transparency in both directions. - Cd levels have been greatly reduced within REVAQ. One of the lowest limits in the world. - 34% of the sludge produced in Sweden is used on agricultural land. Almost all sludge that is spread on agricultural land is REVAQ-certified.	- Initiated at the same time as REVAQ by JTI now RISE - Decentralized system (on-site). Designed for small and source-separated systems. Not complex and costly as REVAQ. - Only household wastes—blackwater (source separated fractions). - Much more simplified than REVAQ. - Demands quality check for biofertilizers. Has demands on tests for heavy metals (as with REVAQ), traceability, and hygienization. - Only few farmers (< 5) farmers are engaged. - Quantity and nutrient content of biofertilizer is very low and does not meet the need of a single farmer. Hence not an important source of plant nutrients. Farmers need to be paid to take care of sludge.

system exists for on-site or decentralized treatment of source separated fractions of blackwater[8]. This is the SPCR 178 which is implemented at a relatively small scale at farm level in a few regions to certify biofertilizers with greatly reduced pathogenic and pharmaceutical content. The farm, Nackunga Gård in Hölö is a prominent example of SPCR 178 implementation (RISE, 2019). **Table 2** summarizes the origin, scope, and key elements of the two certification systems.

In addition, long-term field trials on spreading sewage sludge on agricultural land in Southern Sweden (Skåne) have been going on since 1981 (Andersson, 2015; Österås et al., 2015). These field trials reveal that certain contaminants such as PFAS accumulate in soil upon repeated spreading of sewage sludge over time but the levels in soil after long-term spreading do not pose a risk to the soil ecosystem or humans (Österås et al., 2015). Further, a general increase in crop yield of about 7% with the spreading of sewage sludge was reported from farms in these trials and no negative effects were observed on plant uptake of heavy metals (Andersson, 2015). Similar trials in Denmark show that sewage sludge does not impede the health and reproduction of earthworms and other soil fauna (Pedersen et al., 2019).

The above-mentioned innovative certification systems, including evidence from long-term field trials on spreading of sewage sludge on agricultural land in different contexts are key arguments often raised by proponents to support claims for the use of sewage sludge as a valuable agricultural input. Albeit continuous improvement of the quality of the Swedish sewage sludge through, for example, the REVAQ-certification system including drastic reduction in Cd levels, and evidence from the long-term field trials, opponents of the practice insist that the potential risks associated with the practice remain unacceptable in short and long-term and warn against the "cocktail effects"[9] of these substances (Wallenberg and Eksvärd, 2018; Pedersen et al., 2019). These concerns pertain to a large extent to non-degradable microplastics, pharmaceuticals, and PFAS which originate from different "upstream" activities in society. Microplastics for instance originate from various sources including synthetic clothing, cosmetic products, toothpaste, and other non-point sources such as stormwater[10] (Browne et al., 2011; Talvitie et al., 2017; SAM, 2018). A large proportion of these microplastics end up in WWTPs and subsequently in sewage sludge. This is largely because wastewater collection including stormwater and water from industries and transportation systems in large city centers are predominantly combined and the treatment processes are largely end of pipe[11] with inadequate upstream source separation of waste fractions. Notwithstanding, tertiary treatment of wastewater at WWTPs is reported to remove about 90% of microplastics (Carr et al., 2016; Nizzetto et al., 2016; Hale, 2018). The remaining microplastics are transported in sewage sludge, large proportions of which are destined to end up in terrestrial environments if sewage sludge is applied on agricultural land. Growing international concerns about the risks of microplastics in waste streams and sewage sludge underline the need for further studies and innovative techniques to reduce or prohibit them at the source ("upstream" work), extract them from sewage sludge, and measure and monitor their behavior and impact on terrestrial and aquatic ecosystems (Carr et al., 2016; Gies et al., 2018; Pedersen et al., 2019). As a result, the Swedish Chemicals Agency (Kemikalieinspektionen) instituted a ban in July 2018 on rinse-off products containing microbeads e.g., in toothpastes, body scrubs, shower gels, shampoos, and conditioners. Kemikalieinspektionen is also considering extending the ban to all products that release microplastics and has made proposals for harmonized action at the EU level

[8]Mixture of excreta and flush water along with anal cleansing water (if water is used for cleansing) and/or dry cleansing materials.
[9]Combination of chemicals and substances in humans, animals, and environment.
[10]Rainfall runoff collected from roofs, roads, and other surfaces.
[11]Approach to pollution control which concentrates upon effluent treatment or filtration at the point of discharge into the environment, as opposed to making changes upstream in the process giving rise to the wastes.

(SAM, 2018). Apart from microplastics, other substances such as PFAS which are extremely persistent and have high reproductive toxicity are receiving increasing international attention and merit similar action (Buck et al., 2011; Posner et al., 2013; EFSA CONTAM Panel et al., 2020; European Food Safety Authority (EFSA), 2020). Since Sweden relies largely on food imports, regional focus, and action at the EU level are relevant and worth emphasizing as there are relatively higher levels of heavy metals, Cd in particular and other contaminants in sewage sludge that is spread in other countries (SOU, 2020:3).

Much is known about the actual and potential risks that some toxic substances notably heavy metals in sewage sludge pose, but there are still a lot of unknowns and uncertainties about several other substances that are increasingly being discovered in sewage sludge (Gies et al., 2018; Hale, 2018; Pedersen et al., 2019). Moreover, unfamiliarity and uncontrollability in terms of handling, managing, and measuring risks remain causes for concern and these usually manifest publicly as dread, danger, and stigma (Flynn et al., 2001; Gregory et al., 2001; Kasperson et al., 2001; Science Communication Unit (SCU) et al., 2014). These constitute important categories of special societal concern which have direct and indirect costs to individuals and society in general (Wolff, 2006). From a risk perception point of view, dread, danger, unknowns, and uncertainty determine the type and magnitude of risk people can tolerate and play a role in shaping public perceptions and policy directions (Renn, 2008; Smith et al., 2011; Science Communication Unit (SCU) et al., 2014). Dread refers to potentially catastrophic, uncontrollable and involuntary characteristics of risk, whereas unknown is an unfamiliar characteristic of risk (Bickerstaff, 2004; Frewer, 2004; Science Communication Unit (SCU) et al., 2014). Danger is a type of rejection motivated by anticipated harmful consequences (Rozin and Fallon, 1987). Uncertainty is closely related to risk and in many theories of behavior, psychological uncertainty is assumed to be an important mediator of human responses in situations with unknown outcomes (Sjöberg et al., 2004). These occur as a result of a complex combination of social, cultural, political, emotional, and intuitive factors (Renn and Rohrmann, 2000) which relate to three fundamental types of risks that humans depend on for guidance—risk as a feeling, which refers to fast, instinctive, and intuitive reactions to danger ("fast system"); risk as analysis, which involves logic, reason, and scientific deliberation to bear on hazard management ("slow system"); and risk as politics, which becomes evident when our ancient instincts and modern scientific analysis clash (Slovic, 2010). Even though each of these dimensions of risk is useful in explaining different psychological mechanisms or processes of human behavior, judgment and decision-making under different circumstances, affective reactions to stimulus are often the very first reactions, occurring automatically and subsequently guiding information processing and judgment (Zajonc, 1980; Murphy and Zajonc, 1993).

Risk means different things to different individuals (Slovic, 1987), and under uncertainty and complexity, individuals have the tendency to use logically simpler judgments as a substitute for more complex assessments. This is referred to as "attribute substitution" and is characterized by a shift from a complex mode of deliberation or rational thinking which demands effort in making sense of complex situations to a fast, simpler mode which is automatic, affective, and effortless (Slovic et al., 2004; Kahneman, 2011). This shift may lead to biases in judgment and decision-making and at times policy failures (Strassheim, 2019). Further, this shift challenges the notion that mere utility of an innovation leads to acceptance and adoption of that innovation (O'Keefe et al., 2015; Ekane, 2020). For instance, in the case of the use of excreta as fertilizer in agriculture Ekane et al. (2016) show that individuals do not rely only on risk management information they receive concerning excreta and related risks but also depend, to an extent, on their feelings about these substances when making judgments and decisions regarding the purpose for using excreta as fertilizer and the level of exposure they can tolerate and manage. This is explained by the inverse relationship between risk and benefits in a person's mind (Slovic, 2000; Slovic et al., 2002, 2004; Ekane et al., 2016).

Wastes of human origin in general and sewage sludge in particular are marked by strong or negative images by virtue of their nature and characteristics. These negative sensory images and properties evoke disgust and stigma (Angyal, 1941; Rozin and Fallon, 1981, 1987; Rockefeller, 1998; De Barra, 2011; Curtis, 2013; Rozin et al., 2015; Ekane et al., 2016). As a result, the mere thought of the origin and content of sewage sludge and the practice of spreading sewage sludge on agricultural land particularly for food crop production renders the practice shunned and avoided (Ekane et al., 2016). Further, the anticipation of harm or fear of contamination and the feeling of disgust regarding the practice engenders consequences for the body and psyche, respectively (Rozin and Fallon, 1987). From a psycho-social standpoint, the spreading of sewage sludge on agricultural land is a good example of a stigmatized practice and this partly explains why the practice is embroiled in controversy and opposition as exemplified by the ongoing debate in Sweden. At the heart of this are ingredients for risk-induced stigma and social amplification of risk which emanate from numerous social mechanisms that give people the feeling that risks are much higher or lower than they actually are (Pidgeon et al., 2003). These occur in three steps: a risk-related practice or product that commands attention is made salient and given visibility by altering the risk perception imagery and identity; the product or practice associated with the risk becomes marked through messaging and identified as different and deviant; and the messaging whether amplified or attenuated alters the identity of the product and practice and shapes perception (Kasperson et al., 2001; Slovic et al., 2004). Individuals and networks play key roles in either amplifying or attenuating risks. These occur through institutions and organizations including the media which are major nodes for value-based interpretations influenced in most cases by heuristics and biases (Kasperson et al., 2001; BIT, 2018). A good example is cognitive biases of experts and policy-makers which manifest in various forms including the way problems are framed, the attention and salience given to certain issues, perceiving and interpreting evidence in line with certain views (confirmation bias), conforming to group majority view (group reinforcement and inter group opposition), assuming general support for certain policy choices (illusion of similarity), and overestimating ability to succeed and control outcomes (illusion of control) (BIT, 2018; Strassheim, 2019).

The analysis and discussion in the remainder of this article draw on the theoretical background outlined above as a lens to improve understanding on 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.

METHODS

The study draws on qualitative methods to collect data. These include: (1) a desk-top review of relevant literature on sewage sludge management with specific emphasis on the Swedish context, with risk perception, and risk governance as the theoretical underpinning; and (2) semi-structured in-depth interviews with selected key stakeholders involved in or not involved at all in sewage sludge management in the Stockholm and Uppsala regions. The selection of interviewees was informed by experts within the Bonus Return project and based on previous stakeholder mappings. A total of 17 in-depth interviews were conducted during January to March 2020. Fourteen interviews were done face to face and the rest by telephone. A complete report of the study was shared with the interviewees as part of the process of validating the content and obtaining consent to publish the findings. The selected interviewees are presented and grouped in different categories of stakeholders in **Table 3**. These groupings of stakeholders are predominantly used in the remainder of this article.

Consumers were not part of the target group of this study. The following aspects were discussed during the interviews: extent to which farmers depend on sewage sludge as an agricultural input; how farmers understand and explain the use of sewage sludge in agriculture and factors influencing their perceptions and choices regarding the practice (drivers of the practice, difficulties with the practice, and factors that deter the practice); organizational arrangements and institutional frameworks including compliance regimes; the future of sewage sludge management in line with the recommended options of the recent inquiry and implications thereof.

TABLE 3 | Stakeholders interviewed.

Type of stakeholder	Name of organization/agency/Institute
Farmer 1	Vansta Lantbruk AB (spreading REVAQ-certified sludge)
Farmer 2	Taxinge Gods AB (spreading REVAQ-certified sludge)
Farmer 3	Nackunga Gård (spreading SPCR 178-certified biofertilizer)
Farmer 4	Villberga Kårsta 1 (spreading neither sewage sludge nor biofertilizer)
Farmers' cooperative	Federation of Swedish Farmers (LRF)
Food retailer	Lantmännen
Consultant 1	Inacre
Consultant 2	Advanced Aerobic Technology or A2T (SPCR 178-certified biofertilizer production)
Research institute	RISE or Research Institutes of Sweden AB
Entrepreneur	Ragn-Sells (REVAQ-certified sewage sludge management)
WWTP 1	Käppalaförbundet
WWTP 2	Svenskt Vatten
WWTP 3	Uppsala Vatten
Government agency/regulator 1	Naturvårdsverket or the Swedish Environmental Protection Agency
Government agency/regulator 2	Kemikalieinspektionen
Non-governmental Organization (NGO)	Naturskyddsföreningen or the Swedish Society for Nature Conservation
Media	VA-tidskriften Cirkulation

FINDINGS AND DISCUSSION

Table 4 presents the views of interviewees on the drivers of the practice, difficulties with the practice, and factors that deter the practice.

Spreading sewage sludge on agricultural land, from an environmental standpoint, is an important way of recirculating nutrients and organic matter to grow crops. The need for this closed loop system is well-reported by interviewees as shown in **Table 4**. But if this practice is so viable why is it not widespread? Most interviewees also highlight the risks of contamination or danger with the practice (i.e., harm to the body), the challenges working with sludge, and the disgust or unappealing image it carries with it (i.e., effect on the psyche). In terms of the actual risks and control of these risks, the farmers engaged in the spreading of REVAQ-certified sludge trust that the REVAQ system controls some of the major risks and that the sludge they receive is safe for spreading on their land. This represents one of the prime objectives of the REVAQ-certification system which is to build trust and confidence with farmers. In terms of the social appeal of the practice, many interviewees report that it evokes negative emotions (disgust) and is stigmatized. Yet, some farmers engaged in the practice seem to make a risk benefit tradeoff which is explained by the inverse relationship between risk and benefits in the minds of these farmers (Slovic, 2000; Slovic et al., 2002, 2004; Ekane et al., 2016). To exemplify this tradeoff, farmer 1 who is engaged in spreading REVAQ-certified sludge argues that—*"It is a risk worth taking and is more about how we feel about the practice than how we understand the practice."* To make this point even more concrete the farmer adds that—*"spraying pesticides on crops may be more dangerous than spreading sludge as an agricultural input, but spraying pesticides is an acceptable risk for many people."* Here, the farmer emphasizes that lack of awareness on the practice and the benefits that can be derived from it are factors that deter farmers. A similar argument is raised by Farmer 3, who spreads SPCR178-certified biofertilizer. So, what is particular about sludge that makes it unacceptable if pesticides and sludge both pose risks? The origin, nature, and characteristics of sludge seem to be an important explanatory factor as the expert from WWTP 2 asserts—*"it is more about perceived risks and stigma linked to wastes of human origin (excreta) than the actual*

TABLE 4 | Drivers, difficulties, and deterrents of sewage sludge (REVAQ-certified) and biofertilizers (SPCR 178-certified).

Stakeholders	Drivers	Difficulties	Deterrents
Farmer 1 (spreading REVAQ-certified sludge) (560 ha of farmland. Spreads sludge on–500 ha rented land).	- Soil has low levels of P. - Using sludge for the past 3 years to improve the quality of soil P and organic matter. - Long-term crop cultivation on land. - Cultivates mainly feed—wheat, barley, peas, rapeseed. - Supplies wheat to Lantmännen. - No animal husbandry on land for a long time (no source of readily available manure). - Plans to reduce dependency on chemical fertilizer by 50% in the future.	- Needs to wait 5 years for the release of P since P in sludge is bound to soil. - Satellite maps are hard to do on soil fertilized with sludge.	- Odor produced during spreading of sludge is repugnant. - Stigma is a major issue. - Restrictions in selling crops. Mills are afraid of losing customers and market. - Lack of awareness on benefits that can be derived from sludge. - Concerns of toxic substances e.g., microplastics, pharmaceuticals, hormones.
Farmer 2 (spreading REVAQ-certified sludge)	- Spreading of sludge on land has continued since 1980s. - Spreads sludge every year on the farm but has a crop rotation system wherein he only spreads every 5 years on specific plots. - Nutrient and organic matter content of soil in good quality. Complements with N fertilizer. - No animal husbandry on land (no source of readily available manure). - 800 ha of farmland on which sludge is spread all over. 600 ha is rented land. - Cultivates wheat, barley, malt, oat, rapeseeds, grass mats. - Supplies wheat to Lantmännen.	- Spreading is a messy job and requires dry weather to enable driving through the farm. As such spreading is usually done during the summer. - Receives lower intakes from sales of wheat since it is destined for export. - Would sell for more if wheat is destined for the Swedish market.	Stigmatized practice—negative feelings about the practice keeps farmers away from the spreading of sludge on their farms.
Farmer 3 (spreading SPCR 178-certified biofertilizer). (Farmland of 355 ha, rents 200 ha)	- P, N, and K deficient farmland. - Spreads SPCR 178-certified biofertilizer on only 35 ha (1,500 m^3/year). - Depends to a large extent on chemical fertilizer. - Owns 70 cattle and produces manure (1,300 m^3/year). - Supplies wheat to Lantmännen	The quantity of biofertilizer produced is insufficient to fertilize larger portions of land.	
Farmer 4 (spreading neither sludge nor biofertilizer) (Dairy farmer with 180 ha of farmland)	- Convincing approach of entrepreneurs supplying sludge to farmers to boost crop yield. - Farmers trust that the quality of sludge they receive is good enough.		- Has excess manure. Exchanges manure for straw (100 tons manure for 10 tons of straw). - Milk farms not allowed to spread sludge. - Concerns about substances such as pharmaceuticals and hormones present in sludge. - Has excess manure. Exchanges manure for straw (100 tons manure for 10 tons of straw). - Most neighboring farms >1,000 ha are heavily fertilized with sludge with potential pollution of lake Mälaren. - Repugnant odor from neighboring farms spreading sludge

(Continued)

TABLE 4 | Continued

Stakeholders	Drivers	Difficulties	Deterrents
Farmers' cooperative	- Farmers are not the major drivers and do not demand sludge. - Sludge is presented to them by entrepreneurs who play a key role in convincing those with enough arable land to take up the practice. - About a third of farmers willing to use sludge (on cereals—wheat, barley, oat, rapeseeds).	Farmers face difficulties in selling crops fertilized with sludge because the market in Sweden is limited compared to that for crops fertilized by chemical fertilizers.	- The majority of farmers are either neutral or unwilling to spread sludge on their farms. - Dairy farmers are not interested in sludge because of excess manure e.g., in the West Coast of Sweden and also because of restrictions by the milk production industry.
Food retailer	Nutrients and organic matter		- Reputation of brands. - Sludge not allowed on dairy farms.
Consultant 1	- Nutrient (NPK) deficient soils especially in regions with little or no animal husbandry. - Sludge is favorable for cultivation of cereals for energy and feed much of which is exported. - Farmers engaged in practice are aware that the sludge in Sweden is cleaner than in other countries.	- Farmers are not very conversant about details of REVAQ. But trust authorities and entrepreneurs that supply REVAQ-certified sludge. - Farmers need safe products and want to have guarantee in this regard.	- Sludge is unwanted by most farmers due to risks of microplastics and other toxic substances e.g., Cd bioaccumulation in bones and kidney. - Prohibited for food crop cultivation. - Sludge is not popular in regions with surplus manure e.g., in Western Sweden. In addition, there is low Cd content in the soil in this region. - LRF in Western region is not active in advocating for sludge (LRF does what farmers request).
Consultant 2	Nutrients and organic matter.	Spreading on hired land requires agreement with landowner.	Stigmatized practice.
Research institute	Closing the loop of nutrients from cities to farms.		Unknowns about fate and impact of undesirable substances in sludge.
Entrepreneur (REVAQ-certified sewage sludge management)	- Need for nutrients and organic matter. - Ragn-Sells is a key actor in convincing farmers to engage in the practice.	- Resistance to the storage of sludge in certain areas. - Complaints about odor from storage and spreading of sludge. - Transportation of sludge and other related factors.	- Stigmatized practice. - Practice is not permitted on dairy farms. - Food industry concerned about reputation of brand.
WWTP 1	- Need for nutrients and organic matter. - Need to close the nutrient cycle between the city and the farm	- Difficult to apply with precision as compared to chemical fertilizers. This is because phosphorus in sewage sludge is not readily available as in mineral fertilizers. - Permission is needed from landowner to spread on rented land.	Stigma is a major issue.
WWTP 2	- Vast areas of agricultural land deprived of nutrients e.g., Uppsala, Linköping, Skåne regions. - Need for nutrients and organic matter. - Gradual increase in interest in REVAQ-certified sludge over the years. Substitutes about 20% of chemical fertilizers. - Accepted for growth of cereals as feed and not for human consumption.		- Practice not popular in Regions with excess manure from animal husbandry e.g., Swedish West coast where there is a push for a ban on the practice. - Stigma and perceived risks. - Food industry concerned about long-term effects on market and reputation of brand. - Organic farmers are not allowed to use sludge. - Sludge not permitted on carrots, potatoes, and vegetables.
WWTP 3	- Nutrient (NPK) deficient soils. - Animal husbandry is not predominant (little or no manure). - Clay soil type.		Uncertainty about microplastics, PFAS and other toxics substances in sludge.

(Continued)

TABLE 4 | Continued

Stakeholders	Drivers	Difficulties	Deterrents
Government agency/regulator 1	Nutrients and organic matter.	- Sludge has varying quality and effect is not precise. - Sludge is bulky and difficult to handle. - Odor from practice is repugnant.	- Practice not popular in Regions with excess manure from animal husbandry e.g., Swedish West coast. - Relatively convenient for farmers to work with chemical fertilizers than with sludge.
Government agency/regulator 2	Nutrients and organic matter.	Varying nutrient quality in sludge and thus cannot be used optimally as compared to chemical fertilizers.	- Stigmatized practice. - Unknowns about the number and types of toxic substances of concern in sludge (substances of concern). - There are presently no measures to take off these substances of major concern in sludge. There is also no complete understanding on how these substances react in the ecosystem ("cocktail effects").
Non-governmental Organization (NGO)	Nutrients and organic matter.		- Perceived risks of unwanted substances e.g., PFAS and microplastics in sludge. - No existing protocol to test for all emerging contaminants in sludge. - Farmers are very concerned about the quality of substances they apply on their land.
Cirkulation	Nutrients and organic matter.		- Unknowns about the fate and impact of undesirable substances in sludge. - Nutrients from raw sources (fertilizers) perceived to be purer than those from sludge.

risks.” This a good example of psychological contamination from disgusting objects, with wastes of human origin such as wastewater including faces being universal disgust objects among adults (Angyal, 1941; Rozin and Fallon, 1981, 1987; Rockefeller, 1998; De Barra, 2011; Curtis, 2013; Rozin et al., 2015; Ekane et al., 2016).

Pertaining to the actual risks, while REVAQ-certification requires that heavy metals and microorganisms are reduced in sludge, the experts from the government agencies (regulators), research institute, and NGO emphasize that several other toxic substances present in sewage sludge are not currently being measured and monitored. These knowledge gaps and uncertainties exacerbate the perceived risks for many people as the expert from the NGO reports—*“perceived risks become overwhelming if we do not have control of the actual risks.”* According to this expert, the complex mix (“cocktail effect”) of contaminants such as PFAS, microplastics, and other substances of concern in sludge makes risk analysis difficult. The expert adds that—*“emphasis on heavy metals and salmonella in sludge is a narrow perspective which limits the scope of the REVAQ-certification system and makes it incomplete.”* There is, therefore, a need to identify all possible types of risks and the sources of the substances that pose these risks which are not currently adequately measured and monitored e.g., microplastics, PFAS, and numerous other substances of concern. This is raised by other experts including the informant representing the media who states that—*“pureness beats recycling.”* This implies that increasing concerns about pureness have lessened the importance of recirculating nutrients. This also prompts the question of how safe is safe enough regarding sewage sludge as an agricultural input for different purposes including cultivation of food crops. *“We simply cannot say with certainty the types, characteristics, fate, and impact of most unwanted substances in sludge,”* the expert from the research institute asserts. These uncertainties wield a powerful mark on the practice of spreading sludge, the products of the practice, and even the place where the practice is being carried out. Uncertainties are a possible explanation for why the farmers engaged in the practice apparently have a preference of spreading sludge mainly on rented land which is some form of “not in my backyard approach” (NIMBY). Following Gregory et al. (2001), this type of negative imagery and emotional reaction linked to a practice, product, and place motivates avoidance behavior. To exemplify this even further, this can be said to be the situation in Western Sweden where individuals within the farmers’ cooperative have capitalized on uncertainties and unknowns and are amplifying the risks through the media, debate fora and networks as consultant 1 and the expert from WWTP 2 report. While the expert from the research institute likens the ongoing debate on microplastics and PFAS to the hype about dioxins in the 1980s, the journalist likens it to the climate debate with the proponents attenuating the risks and opponents or skeptics amplifying the risks. These are good examples of the effect of amplification stations which play key roles in interpreting risk and conveying signals that affect people’s perceptions about the seriousness and manageability of risks (Kasperson et al., 2001). The following are some examples of signaling through media coverage that are intended to alter risk perception, imagery, and place identity:

> *Äntligen stopp för slamspridning på åkermark (Finally, a stop to the spreading of sewage sludge on arable land). (03 August 2018)*
>
> *Lägg inte ut giftigt slam på våra åkrar: Regeringen måste säga nej till sin egen utredning (Do not put toxic sludge on our agricultural fields: The government must say no to its own investigation). (05 March 2020)*
>
> *Slammet på åkrarna kontrolleras noga: Replik från återvinningsindustrierna och Svensk Vatten (The sludge that is spread on fields is carefully checked: Response from the recycling industries and Svensk Vatten. (06 March 2020)*
>
> *Slamspridning på åkrar ökar inte risken för antibiotikaresistens (The spreading of sewage sludge on agricultural fields does not increase the risk of antibiotic resistance). (10 February 2020)*

Regarding microplastics and PFAS, the expert from the research institute stresses the need to identify the major sources of these substances in society and not focus solely on possible sources like sludge which may not be so significant. As reported by the expert from the NGO—*"the content of sludge is a reflection of society and its choices."* For instance, the expert highlights that considerable amounts of PFAS are released by fire extinguishers used for firefighting at air force training grounds. This same point is raised by consultant 1. This broadens the scope of the debate to include lifestyle choices and to an extent the quality of food commodities not grown or produced in Sweden. The complexities of controlling imports are raised by the expert from the food retailer industry. For instance, to what extent do importers have control of the quality of agricultural practices and food produced in other countries? And to what extent are consumers aware of the impact of their choices of commodities including food and clothing? These are pertinent questions raised by many interviewees including farmers. According to the expert from the NGO—*"there is need to put high demands on home-grown food and at the same time raise the demands on imported products. Sweden should not wait for other regional or global legislations to become better before taking action on updating the current outdated national sewage sludge legislation to support efforts toward the environmental quality objective of a non-toxic environment."* The complexities of controlling imports are raised by the expert from the food retailer industry.

Further, the results from the interviews reveal spatial differences in the spreading of sludge on agricultural land. This has been shown to depend on the need for the nutrients, interest in using sludge as an agricultural input, location of farm, and restrictions by the food industry. Regarding the need for nutrients and interest in the practice, spreading of sludge is reported to be more accepted in regions with nutrient-deficient soils and with little or no animal husbandry i.e., inadequate access to manure. This is the case for regions like Stockholm, Uppsala, Linköping and parts of Skåne. These regions are highly populated and produce large volumes of sludge that must be managed and disposed. Further, the combined waste collection system in city centers in these regions is raised by the expert from WWTP 2 as a key factor in introducing unwanted substances from waste streams and, therefore, greatly complicates the treatment processes. The Western region on the other hand has predominantly animal husbandry and as a result, excess manure. In addition, the region is reported to have low levels of Cd in the soil. There is, therefore, little or no incentive for farmers in this region to engage in the practice of spreading sludge on their land. The situation in this region is similar to that in Germany and the Netherlands where there are many animals and excess manure (Smits and Woltjer, 2018) and incineration of sludge has taken precedence partly to reduce volumes of sludge. Consultant 1 emphasized that in the case of Germany and the Netherlands, the governments or national agencies exert authority on whether sludge is to be used use or not. This is not the case in Sweden where farmers spreading sludge decide to engage in the practice based on their preferences and the market for sludge fertilized crops. In terms of restrictions, the food industry notably the dairy industry is against the use of REVAQ-certified sludge on the same land as for milk production. This is mainly due to the fear of contamination, brand reputation, and fear of losing customers. However, as the entrepreneur reports—*"feed can be cultivated with REVAQ-certified sludge on a different farm and transported to feed cattle on the milk farm."* This is also raised by the expert from the food retailer industry who adds that Sweden is a major exporter of cereals most of which are grown using REVAQ-certified sludge. The way the cereals are used by their customers depends on the quality parameters e.g., protein levels.

Figures 1, **2** illustrate the organizational arrangements, and roles and responsibilities of different actors involved in spreading REVAQ-certified sludge and SPCR 178-certified biofertilizers, respectively. **Table 5** further outlines considerations with the two certification systems with details from the farmers that were interviewed. Results from the interviews reveal that farmers are not the major drivers of the practice. According to the expert from the farmer's cooperative—*"Farmers do not make demands for sludge. By themselves, they would not go for sludge."* This points to the role that other actors play in promoting, monitoring, and evaluating the practice. An important part in this process is the building of trust and convincing farmers to engage in the practice which is a key role of entrepreneurs and many others in the branch such as Biototal, HD BioRec, Kuskatorpet Entreprenad och Lantbruk AB, MEWAB AB. As outcome of this process, contracts are brokered with farmers either directly through contracts with the WWTPs, for example WWTP 1 in the case of farmer 1 or indirectly through entrepreneurs in the case of farmer 2 (about 5 farms are involved in the former). Also, as part of this process, farmers are informed of their responsibility to explore possibilities of marketing their produce with the food retailer. Farmers supplying cereals to the food retailer are required during delivery to declare the source of agricultural produce and indicate whether they have been fertilized with REVAQ-certified sludge or not. This is, however, difficult to ascertain as reported by farmer 4 who is not engaged in spreading sludge—*"there are no guarantees that all farmers report if they have used sludge or not upon delivery of cereals."* This questions the aspect of trust which is supposed to be one of the pillars for this collaboration. This is even more pertinent as the farmer 2 informs that they

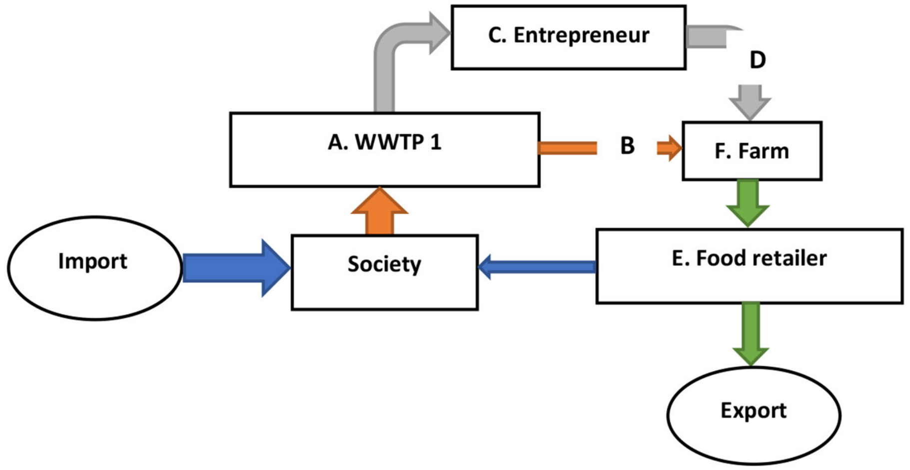

FIGURE 1 | Distribution of REVAQ-certified sludge—WWTP to farm and farm to market.

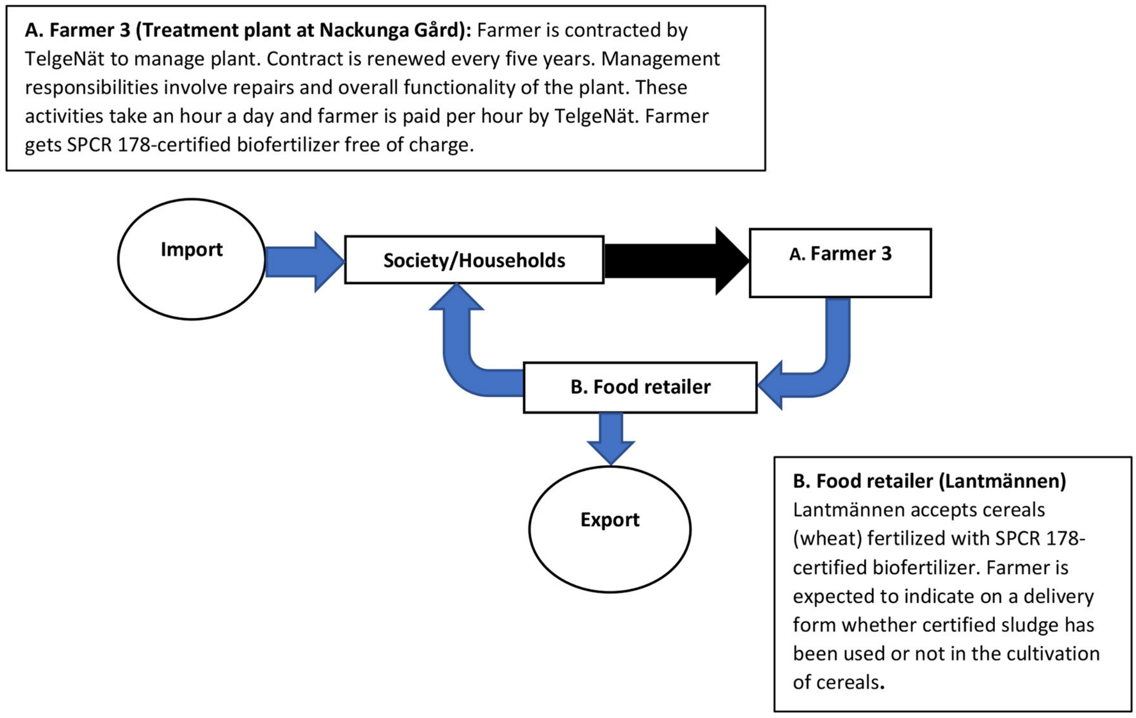

FIGURE 2 | Processes for SPCR 178-certified biofertilize—treatment plant to Farm and Farm to Market.

get more intake from cereals destined for the Swedish market than for those destined for export. The expert from the food retailer industry confirms that there is no control mechanism to trace or verify that what is reported upon delivery of cereals is correct but emphasized that the system is based on mutual trust. But such a concern about transparency and trust would need more attention as the expert from the NGO contends– *"consumers have the right to know what is used in producing their food."*

Table 6 outlines the views of interviewees regarding the options recommended in the most recent inquiry commissioned by the Swedish government (SOU, 2020:3).

As can be discerned from **Table 6**, there is a general preference for option 2 with stricter regulations and emphasis on "upstream" work including source control. This is plausible from a resource point of view and as interviewees indicate, it opens up for innovative research and development. In line with the Swedish environmental objectives, this puts even higher demands on

TABLE 5 | Different arrangements in the certification systems.

Stakeholders	REVAQ	SPCR 178
Farmer 1 (spreading REVAQ-certified sludge)	- Contract with Käppalaförbundet. - Receives about 1.000 tons of certified sludge each year directly from Käppalaverket. - Sludge is stored on-site for at least 6 months. - Spreads 13 tons/ha every 5 years depending on soil nutrient content (with a limit of 22 kg P/year). - Receives SEK 100/ton for storage, handling, and spreading. - Spreading is done by farmer. - Practice ongoing for 3 years.	
Farmer 2 (spreading REVAQ-certified sludge)	- Contract with Ragn-Sells. - Receives about 2,000 tons of certified sludge from Ragn-Sells each year. - Initially had a contract with Käppalaförbundet. - Stores sludge on-site for 6 months on farm. - Spreads on all 800 ha farmland (owned and hired). - Spreads 10–20 tons/ha every 5 years depending on soil nutrient content (with a limit of 22 kg P/year). - Ragn-Sells pays SEK 40/ton for spreading. - Spreading is done by the farmer.	
Farmer 3 (spreading SPCR 178-certified biofertilizer)		- Contract with TelgeNät to manage treatment plant. - Management contract of plant renewed every 5 years. - Biofertilizer produced onsite by wet composting plant. - Spreads 35 tons/ha/year of biofertilizer.

pre-treatment and prevention of unwanted substances from all sources from getting into waste streams. Also, a shift from combined to separate wastewater collection and treatment systems would greatly facilitate and reduce treatment costs. The decentralized SPCR 178-certification system for blackwater is an example of such a shift. Further, some interviewees observe that stricter regulations offer possibilities for further development of the REVAQ-certification system which is already of high standard compared to other countries and has contributed to marked improvement in sludge quality. *"Averagely, wastewater from households is of poorer quality than that from industries as a result of higher demands for pre-treatment in industries within the current REVAQ-certification system,"* the expert from the research institute said. However, costs associated with REVAQ-certification remain a major issue as farmer 1 observes,—*"It is quite expensive to be REVAQ-certified. This can easily be managed by larger WWTPs than smaller ones."* The cost of creating a stricter compliance regime as recommended in the inquiry is further raised by a number of interviewees. Like many of the interviewees, the expert from the farmers' cooperative is of the opinion that households connected to the centralized systems should bear the costs. Most of the interviewees even add that it could be in the form of VA Taxa[12].

From a risk point of view, a complete ban is perceived by some interviewees, notably the experts from the government agency/regulator 2 and NGO as a safe way of dealing with the uncertainties and unknowns in sludge. This stance can be explained by the strategic roles and responsibilities these stakeholders play in monitoring and regulating toxic substances in society and the actual and potential risks. Some interviewees made reference to technological options such as incineration as is done in Germany, the Netherlands and Switzerland. Albeit the merits of incineration, several drawbacks were raised by interviewees, namely that it is unsustainable, expensive, and energy demanding, leads to lock-in and blocks innovation and discourages research. The expert from the research institute describes the potential ban as an "end of pipe control" which will discourage source control and make the REVAQ-certification system irrelevant. Moreover, recovered P from ash in the incineration process will most likely be expensive and thus unattractive to farmers. *"If the cost of P fertilizer increases, there is a likelihood that farmers will not buy it,"* farmer 1 reported.

According to the expert from the government agency 1, some of the conclusions drawn in the 2020 inquiry are similar to those drawn in the Naturvårdsverket Rapport 6580 in 2013 wherein the need to improve hygienisation and upstream work were emphasized. The expert adds that a broader scope of the inquiry to include other flows e.g., food and food wastes and not just sewage sludge is a logical way forward. This also points to the need to trace contaminants in imported food.

The purpose of the most recent inquiry is questioned by the expert from the government agency 1—*"why do we need this new inquiry when we have not taken concrete actions on the previous inquiries?"* In addition, the expert from the NGO observed that—*"the directive from the government regarding the ongoing inquiry was not whether there should be a ban but rather how the ban should look like."* Therefore, highlighting nutrient recovery for instance without further elaborating recirculation as in the report

TABLE 6 | Perceptions on the options presented in the recent inquiry (SOU, 2020:3)[13].

Stakeholders	Option 1: Complete ban with very few exceptions	Option 2: Ban on condition that possible risks are to be managed and addressed	Stance on the ban
Farmer 1 (spreading REVAQ-certified sludge)	Farmers unable to exploit the resources in sludge	- Costs will increase. This increase cost will be borne by others and not farmers as farmers are already dealing with lots of restrictions. - Farmers should be allowed to contribute in formulating these restrictions. - Costs of meeting REVAQ requirements are already quite high.	Option 2
Farmer 2 (spreading REVAQ-certified sludge)	- Missed opportunity. In the case of incineration, the costs may even be much higher than stricter regulations. - Quality control for imported food needs to be equally strict in tracing food that is fertilized with sludge.	- Puts higher demands on upstream work which will eventually increase management cost. - Tax-payers to cover this cost through the VA taxa (water and sewage tax)[12].	Option 2
Farmer 3 (spreading SPCR 178-certified biofertilizer)	Blocks possibilities for closing the loop	- Logical way forward but will involve increased costs for stakeholders. - Requires innovations in agricultural systems and compliance. - School system needs to incorporate module to educate children about origin of food and how nutrients circulate in the agricultural system. - The quality of imported food needs further attention since the farming systems and working conditions vary from one country to another.	Option 2
Farmer 4 (spreading neither sludge nor biofertilizer)		More sustainable option.	Option 2
Farmers' cooperative	- Certification is preferable. - The purpose of REVAQ-certification is to avoid a ban by emphasizing upstream work and improving the quality of sludge. Cd levels have been greatly reduced through REVAQ-certification.	- The food industry should take more responsibility in shaping this process. - Upstream work is crucial. Consumer consciousness and shared responsibility should be emphasized. - WWTPs should cater for any eventual increases in cost.	Option 2[14]
Food retailer	Expensive and would lead to lock-in.	Places emphasis on source separation (upstream work).	Option 2
Consultant 1	- Preferable to place emphasis on certification of process and product just as in REVAQ-certification. - Since municipalities are not obliged to report on the fate of sludge, there is a likelihood for illegal spreading (No need to create a situation whereby compliance becomes a big issue).	- Even more emphasis on upstream work e.g., with REVAQ (centralized system) and source separation like H+ development in Helsingborg (decentralized system). - Strict demand for reporting and transparency on origin and fate of sludge. - Suggests a 5-year period for Naturvårdsverket to formulate limit values building on the REVAQ system and improve on the quality of process to allow nutrients to be returned to the soil. - Any increase in price for P fertilizers from sludge would be unattractive to farmers. - - Increased costs should be borne by the WWTP-collective.	Option 2
Consultant 2	- Can be considered as business as usual. - Closes room for innovation and makes upstream work irrelevant. - Huge costs associated with options like incineration.	- Place emphasis on upstream work. e.g., with REVAQ (centralized system) and source separation like H+ development in Helsingborg (decentralized system). - Opens up for innovation, further research and development. - Presents opportunity and widens focus to include many other nutrients and not only P.	Option 2

(Continued)

[12] *Vatten- och avloppstaxan (water and sewage tax). This was recently increased on 1 January 2020 by 5% in Stockholm and Huddinge municipalities.*
[13] *Options presented in the inquiry are also outlined in* ***Table 1***.
[14] *The farmers' cooperative responds to the needs of their farmers.*

TABLE 6 | Continued

Stakeholders	Option 1: Complete ban with very few exceptions	Option 2: Ban on condition that possible risks are to be managed and addressed	Stance on the ban
Research institute	- This is "end-of-the- pipe control." May discourage source control and make REVAQ irrelevant. - Direct implication is incineration which is a costly process and will lead to lock-in. - Identification of new substances that find their way in sludge may not happen since a robust monitoring system may not be in place.	- Source control (upstream work) takes precedence. - Emphasis on analysis and follow-up mechanism. - Increased research and innovation especially with respect to microplastics, PFAS and other toxic substances of concern in sludge. - Promotes recirculation of nutrients in agricultural systems.	Option 2
Entrepreneur (REVAQ-certified sewage sludge management)	- Regulations on sludge are more focused on origins of sludge than on the quality of sludge. - Incineration is a possible option but requires transformation of current operation. This will increase cost of sludge treatment.	- Even more emphasis on upstream work. - Opens up for more innovation and competition. - Increased costs could be covered by VA taxa. - Focus on recycling and quality.	Option 2
WWTP 1	Incineration may be the option. No full-scale solutions for nutrient recycling from aches developed yet. Would take away an important driving force for upstream work-	Point source pollution from industry has been greatly reduced. Even more emphasis to be placed on upstream work. <source control at household level is the way forward.	Option 2
WWTP 2	Waste management costs will increase. Provides incentive for incineration.	Places emphasis on upstream work and a revision of REVAQ. New regulation would be costly to meet. Cost to be borne by customers.	Option 2
WWTP 3	Costly process and would require a drastic change in waste management operations.	Additional monitoring and measuring procedures (for PFAS and other substances of concern) to operations of WWTPs would not be a drastic change.	Option 2
Government agency/regulator 1	- Compromises upstream work. - Need to put high demands on imported food at the same level as for Swedish grown food.	- Build on previous inquiries e.g., 2013 and further developing REVAQ (with clear limits on hygienization and source control or upstream work) for possible export to other EU countries. - Increase subsidies to the sector to cater for the costs associated with stricter restrictions. For instance, distributing the recovered P from sludge for free. - Waste producers may also pay for increased costs in the system. - Need for more active measures with a Top-down approach e.g., like in Germany (the Swedish approach is Bottom-up)	Option 2
Government agency/regulator 2	In the absence of facts or complete picture about the types, nature, and fate of PFAS and substances of concern in sludge and methods of monitoring them, this option is in line with the objective of "non-toxic environment."	Emphasis on upstream work.	Option 1
Non-governmental Organization (NGO)	- Current sewage management practices must be improved. - Objective of inquiry is not properly addressed. Inquiry was intended to show how a ban should look like and Not if there should be a ban. - There is a need to emphasize high demands on what is produced in Sweden as well as raising the demands on imported products.	- Either of the two options presented in the inquiry is an improvement from the current situation. - Upstream work should be emphasized. - Take "cocktail" effects of undesirable substances into consideration. All toxic substances in sludge should be tested. - Increased costs could be borne by raising VA taxa (Polluter pay principle). This can only increase willingness to pay at household level if the industry is doing the same. - Consumers would have to know what their food is produced of. - Trust in the treatment system needs strict enforcement.	Option 1
Media	- Safety concerns open up for solutions such as incineration e.g., German case. Incineration sludge (with moisture content) is an expensive venture. - P may be extracted from ash but organic matter and N will be lost.	- Opens up for innovation and will depend on what the standards would be and how they will be enforced. - There is a possibility of REVAQ being replaced by a new standard. This will impose higher costs and tougher demands. Increase costs to be borne by VA taxa or government subsidies through the municipalities	Option 2

of the inquiry indicates that there is more work to be done in this respect.

CONCLUSION

Sewage sludge presents both benefits and risks as this study shows. This is the same for other agricultural inputs such as cattle manure and pig slurry which are relatively more acceptable and widely used. As this study contends, sewage sludge is marked and stigmatized as a result of its origin, nature, and characteristics, and this has implications on the use of sludge on agricultural land. This also relates to uncertainties, unknowns, and unfamiliarity regarding the nature, characteristics, and fate of unwanted substances in sludge. These manifest as dread, fear, and psychological contamination and merit attention as these play a critical role in shaping public perceptions. Facts, fears, and feelings make issues salient and shape public perception in very important ways, as the ongoing debate in Sweden on this matter reveals. Both sides of the debate have something to say in terms of the viability and safety of the practice and controllability and severity of the risks. Notwithstanding, what remains influential is that perceived risks take precedence in situations of unknowns, uncertainties, and unfamiliarity regarding characteristics, fate of toxic substances such as microplastics, PFAS, substances of concern including potential “cocktail effects” and the absence of appropriate methods or systems for monitoring and measuring these effects. This explains the restrictions by the food industry e.g., Arla Foods to prevent physical contamination, maintain brands, and keep customers. Also, the fact that a ban on the practice is on the table and being discussed stems from this. As can be discerned from the stance on the ban on sewage sludge, some farmers, entrepreneurs, and consultants emphasize the benefits of sewage sludge as a resource and stress the need for improvements in the risk management system. On the other hand, the NGO and one of the government agencies monitoring and regulating toxic substances in society emphasize the gaps in monitoring and minimizing risks and would rather have a complete ban on the spreading of sewage sludge on agricultural land.

As this study shows, context matters and is key in understanding the drivers and deterrents of the practice of spreading sludge on agricultural land. The regional differences between Western Sweden and the Uppsala, Linköping, and parts of Skåne regions are good illustrations of this. This is also the case in Germany and the Netherlands which both have a top-down approach in dealing with sewage sludge. This points to the fact that a regional approach to formulating regulations on sludge management may well be a democratic way to proceed in the case of Sweden. On the other hand, top-down approaches in updating policy and possibly formalizing compliance regimes like the REVAQ and SPCR 178-certification systems may be problematic.

The contention between facts about actual and perceived risks and benefits of recirculating nutrients in agricultural systems is also a major factor that may have implications on public perception. This is made even more salient through social amplification of risk within different expert networks including the media. It is, therefore, important for experts and journalists in their communication of facts to the general public on this matter to relate their claims or stance to something understandable to avoid propagating exaggerated fear. This is an important insight for risk communication.

A market driven approach seems to be the major driver for the spreading of sewage sludge on agricultural land with entrepreneurs playing key roles in driving the practice. As key actors but not major drivers of the practice, farmers engaged in the practice rely largely on certification systems such as the REVAQ-certification system which has greatly improved the quality of sludge. Most importantly, transparency and mutual trust in the quality of what farmers receive as certified sludge and what they produce as cereals is worth emphasizing and is key for the system to function, knowing well that once trust is lost it is extremely difficult to recover.

This study reveals preference for stricter regulations as opposed to option 1 or “end of pipe control” in managing sewage sludge. In line with this preference, major societal, technological, and policy changes would need to be implemented. Some of the key conditions to accompany this change include shared responsibilities in terms of costs of the innovation and desired transformation, strengthened mutual trust in the compliance regime that will be instituted, improved techniques and systems for monitoring and minimizing risks of unwanted substances in sludge, and oversight on the contribution of different societal activities to the problem. Moreover, the viability of upstream solutions, such as source separation or even future work with REVAQ requires further investigation. Further, since farmers or the food industry are unlikely to bear the cost for major changes in the system partly as a result of international competition on food prices, increased costs will undoubtedly fall on society and households. It is worth noting that attaining all these conditions is unlikely in a short term and as such option 1 may well be the safe way forward in line with the Swedish environmental objective to create and maintain a non-toxic environment. Highlighting the benefits of sewage sludge in agriculture is important but not enough to drive the practice. It is even more important to show that risks are well-understood and controllable in short and long-term. Irrespective of the pathway Sweden decides to take regarding the fate of sewage sludge, stricter measures must also be taken at the international level to trace and monitor unwanted substances in food imported from other countries with much weaker regulations on the use of sewage sludge on agricultural land. This is a gap that this study highlights.

We conclude that a complex combination of technical, environmental, socio-economical, psychological, and political factors play an important role in judgment and decision-making regarding sewage sludge and its safe use as fertilizer in agriculture. Technically, it is about the availability and effectiveness of techniques and systems for monitoring and minimizing risks and at the same time harnessing nutrients e.g., P; environmentally, it is more about aiming for sustainability and at the same time maintaining pureness; socio-economically, it is about market viability of nutrients harnessed from sludge in comparison with nutrients from other sources as well as the acceptability by food industry and consumers; politically, it is about the contention that emanates from the clash between facts and feelings about the practice and the implications for public trust.

This study is limited in that consumer perceptions were not included. This was not part of the objective of this study but is an important part of the puzzle which merits further studies. In addition, this is a case study with selected experts and farmers from only two regions in Sweden. Thus, the recommendations may not be generalizable for the whole of Sweden. However, with their expertise and backgrounds from different levels within the sector, their insights give a good understanding of the institutional and organizational aspects of sludge management and the facts and fears in the ongoing resource vs. risk debate.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

NE designed and conducted the study and wrote the article. KB and AR provided invaluable inputs during the conception of the study and the writing of the article. All authors contributed to the article and approved the submitted version.

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