Research article

Should the Sludge Hit the Farm? – How Chemo-Social Relations Affect Policy Efforts to Circulate Phosphorus in Sweden

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A B S T R A C T

This article discerns why the substantial political efforts to increase circulation of nutrients in sewage sludge, and phosphorus in particular, have shown such meager results over the last twenty years in Sweden. We have analyzed stakeholders’ statements of opinions to four government-initiated inquiries, to decipher the chemo-social relations between stakeholders and phosphorus, and how these relations have transformed over time and made a difference in the policy process.

In our analysis, we found five different relations: 1) a metabolic, 2) a purity, 3) a nutritional, 4) a marketable, and 5) a geopolitical. These relations connect actors, phosphorus and politics in different ways, and obstruct policymaking by creating tensions between political objectives, values and stakeholder positions.

We observe how the extraction of phosphorus as a singular, marketable element to be sold for profit reasons on a global market, is increasingly favored in comparison to local eco-cycling of nutrients between farmers and consumers. We see this as a consequence of that the circular economy as a concept has replaced eco-cycle efforts in the Swedish policy debate.

We conclude that if circular economy-initiatives are to be successfully implemented, they need to be informed by the current configuration of material flows that they wish to transform as well as the political implications of their efforts. So far, this has not been the case regarding sewage sludge in Sweden.

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1. Introduction

In recent years, the ‘circular economy’ has increasingly been argued for as a conceptual model for how to re-organize resource flows in economies all over the world. Based on the idea that closing material loops equals environmental gains as well as economic benefits (Geissdorfer et al., 2017), the circular economy has been almost unequivocally embraced, from the level of national governments, via non-governmental organizations (NGO), industrial actors and cities (Corvellec et al., 2020). The discourse of circulation is highly relevant also within the agricultural sector (Jurgilevich et al., 2016), where different ways to circulate vital nutrients have been targeted in research, policy as well as practical efforts. In this article, we scrutinize sewage sludge, which is continuously emphasized for its nutrient deposit qualities in agricultural and cultural debates concerning the circular economy (Chergel et al., 2019).

One of the most prominently featured nutrients in sewage sludge is phosphorus, a vital building block in all living organisms and a key ingredient in inorganic fertilizers used in industrial agriculture (Gleason, 2007). Inorganic phosphorus is mined from phosphate bedrock, and the fact that such deposits are depletable and unequally distributed geographically have led to fears that decreasing supplies could result in price shocks and mining of ores of very low quality (Cordell and White, 2011). The European Commission is especially concerned over this (European Commission, 2013), since mining sites within the European Union (EU) are few, and implies a phosphorus dependency on a few other countries, primarily Morocco and its occupied territories of Western Sahara. Therefore, the commission strongly emphasizes increased recycling of domestic phosphorus and has especially targeted sewage sludge as one such deposit (Lipińska, 2018). Implementing initiatives to this cause has however shown to be difficult (see Ranta et al., 2018).
EU member states have chosen opposing ways to adopt the EU-legislation (mainly Council Directive 86/278/EEC (European Economic Community, 1986)), where some countries advocate sewage sludge use in agriculture while others have banned it completely (European Commission, 2001; Hukari et al., 2016; Bauer et al., 2020). The European Commission (2013) has therefore concluded that the current legal framework is outdated and needs harmonization to increase circulation. Initiatives to update these frameworks have been repeated over and over again (European Commission, 2015; European Commission 2020), with little impact.

To understand the difficulties to agree on a common legal framework for circulation of phosphorus from wastewater effluents, this study focuses on national Swedish policy efforts regarding sewage sludge management. Showing equally lackluster results nationally as the EU, the Swedish ambitions to increase phosphorus recycling has challenged the political efforts for a long time (Bengtsson and Tillman, 2004), and the decision makers have so far not been able to reach an agreement. Evidence of the protracted process is for example seen in the four government-initiated inquiries concerning sewage sludge that have been launched during the last two decades (Swedish Environmental Protection Agency (SEPA), 2002, 2010, 2013; Government Offices of Sweden, 2020). These inquiries have had the replacement of inorganic fertilizers by recycled phosphorus and other nutrients from sewage sludge as their major concern. Four inquiries initiated on similar topics in a relatively short timeframe signifies the topic’s relevance in the national debate as well as the difficulties of going from inquiry to policy changes. In this paper, we present our analysis of the statements of opinions from the public consultation phase of these four inquiries.

The objective of the study was to scrutinize why the policy process has had such meager results in its effort to create a transition towards a circular economy in Swedish sewage sludge management. We scrutinized how actors coalesce around certain topics and lines of argument, how they relate to phosphorus, and how these relations affect and obstruct the suggested reconstructions to achieve a more circular economy. Our study was guided by the following research questions:

- Which relations between human actors and phosphorus are detectable in the Swedish policy debate on sewage sludge management during the last 20 years, and how are these relations constituted?
- In what ways do these relations and the actor coalitions around them change over time?
- How do these relations make a difference in the Swedish policymaking process towards a circulating phosphorus?

In the next chapter, we situate the study in a Swedish research context and explain the study’s theoretical underpinnings. Thereafter, we present the gathered material and how it was analyzed. The results are presented under five thematic headlines in chapter 4, and are followed by a discussion of the findings and concluding remarks.

2. Literature review

Previous studies on sewage sludge management and the political efforts to transition towards a more circular economy has drawn our attention to how relations between stakeholders and waste material are established. Scholarly work on material politics (cf. Barry, 2013) and in the field of discard studies (see Liboiron, 2018) is helpful when looking at how so-called “chemo-social relations” affect the political possibilities. This is further elaborated on in the following sections.

2.1. Previous studies

In this article, we are interested in the Swedish circular economy policies in the particular case of sewage sludge phosphorus, a topic which has been the focus of some but not many previous studies. Bengtsson and Tillman (2004) wrote about the debate emerging after the Federation of Swedish Farmers banned all use of sewage sludge as fertilizer. Lennartsson et al. (2019) wrote about the difficulties of introducing source-separation toilets in Sweden, and Nedelciu et al. (2019) mapped various obstacles for phosphorus recovery from sewage sludge in Sweden and Hungary. Barquet et al. (2020) studied barriers and opportunities for phosphorus recycling in the Baltic Sea region. While these studies are relevant to situate our study in contemporary research, we complement these studies with a longer time perspective and focus more broadly on phosphorus circulation. This implies that we are filling a knowledge gap in comparison to previous literature.

In a study of Swedish governmental inquiries with a similar albeit more general focus than ours, Johansson and Henriksson (2020) identify a shift of imputes from closed material loops at the local scale in 1997 to ever increasing global material loops in 2017. Their study has a similar time scope as ours, but while they assess the political efforts on a more strategic level, our study focuses on a particular chemical in a particular waste stream in a particular policy process. This enables us to understand the pre-conditions of how to implement circular economy-initiatives in practice and not only as political ambitions introduced top-down.

2.2. Theoretical underpinnings

Theoretically, we take inspiration from scholars interested in the critical ways in which materials play a part in political decision-making. These scholars argue that studies of decision-making processes should not leave materials outside of the scope of the analysis (cf. Barry, 2013). Our point of departure is therefore similar to what Abrahamsson et al. (2015) has observed, who stress that it “is not so much that materialities are involved in political conundrums, but how they are involved” (Abrahamsson et al., 2015 p. 16).

In the case of the circular economy, the reorganization of linear material flows into circular ones has implications on how actors relate to materials and society (Hultman and Corvellec, 2012). Simultaneously, different ways to conceptualize circularity, i.e. which materials should be circulated by whom, when and where, can result in clashes of various moral ideals. Gregson et al. (2015) for example, find that such ideals collide when local resource cycles are challenged by global recovery markets in their study on EU policy on resource recovery. Furthermore, whichever of the many conceptualization of the circular economy one opts for, has important impacts on whether the policymaking will be more restrictive or deregulated (Nylén and Salminen, 2019).

In our study, we are particularly interested in how phosphorus is involved in various chemo-social relations, a term formulated by Shapiro and Kirksey (2017), and how such relations make a difference in the sewage sludge policy process in Sweden. As a term, chemo-social signifies how humans (societal actors) and chemicals (compounds found in nature) are entangled and interact (Shapiro and Kirksey, 2017), and how these relations are implied in the flows of sewage sludge materials. We attend to the different ways that the act of relating (Strathern, 2014) is articulated by the stakeholders in their statements of opinions, i.e. instances in their written words that make chemo-social relations explicit. The literature on chemo-social relations criticizes earlier approaches in studies of chemicals and society, as “not viable in a permanently polluted world as these focus on local emissions which can be contained, separated, cleaned up, immunized”
(Liboiron and Tironi, 2018 p.332) and where chemicals are treated in isolation. Instead, these scholars argue for the importance of both addressing long standing chemo-social relations of exposure and dependency beyond national borders, as well as emerging new chemo-social identities (Shapiro and Kirksey, 2017). This underscores what Romero et al. (2017), write about chemicals as an important part of a chemical geography and a global metabolism.

A chemo-social perspective furthermore allows us to analyze the shape shifting capacity of phosphorus as both polluting and life giving. We are intent to keep this volatility of phosphorus in play and regard phosphorus in various configurations. In doing so, we adhere to Balayannis and Garnett (2020), who also stress the difficulty of categorizing chemicals in either/or-terms. We argue that phosphorus is a particularly good example of this, as it is both capable of causing eutrophication in bodies of water thus disabling the life of some organisms, and simultaneously enabling other organisms to flourish. Balayannis and Garnett (2020) state that studies of chemo-social relations should involve “a tentativeness towards making normative claims about chemicals because [...] these materials are never entirely good nor bad; they can be both enabling and harmful” (Balayannis and Garnett, 2020 p. 2). We use this tentativeness to avoid the dichotomy often found in previous sewage sludge research where phosphorus is often seen as good, a resource, in contrast to various pollutants, which are bad (cf. Bengtsson and Tillman, 2004, Nedelciu et al., 2019).

### 3. Methods

Our research method relies on an analysis of *statements of opinion* to four governmental initiated inquiries. Statements of opinion are written responses from various stakeholders, and how we collected and delimited this material is further described in the following section. In Section 3.2, we describe our analytical method, i.e. how we did our textual analysis of the empirical material to elicit how the different stakeholders relate to phosphorus in what we call chemo-social relations.

#### 3.1. Gathering the material

Public inquiries are central to Swedish policymaking, and a tool that the government uses to formulate bills on a well-informed basis. Such a government-initiated inquiry is led by a committee responsible for gathering information regarding a certain issue. After an inquiry’s report is presented, stakeholders are welcomed to submit their written feedback: their statements of opinions. These written documents are compiled together with the inquiry report and may constitute the written basis for new legislation (Government Offices of Sweden, 2016). We selected statements of opinions related to four public inquiry reports initiated by the Swedish government on the topic of sewage sludge utilization during the period of 2002 to 2020 (see Table 1).

The political importance of national inquiries implies that actors wanting to influence sewage sludge policy should be interested in submitting their written feedback to them. This makes this kind of written material relevant for our study, given that a great many of the relevant Swedish actors in the sewage sludge debate are present in the material. The fact that statements of opinions are feedback to the government and not opinions raised as a result of open questions makes the material even more relevant given our interest in discerning stakeholders’ stances on a particular issue. Even so, it should be recognized that statements of opinions are steered by what the inquirer have emphasized in their report, and can therefore be tainted by the inquiry’s direction and claims and skewed to not include things that the inquiry perhaps missed or overrode. This is a weakness in the material chosen and could have been avoided if we had chosen to interview the involved actors as well. On the other hand, the reactive nature of these documents evokes strong and well-argued lines of reasoning, which is rewarding when one is interested in analyzing stakeholders’ stances.

The reason why we chose the statement of opinions and not the inquiries themselves, is that they enable an analysis of different actors’ stances and how these change over time. The written statements disclose the stakeholders’ positions and engagements in a way that the inquiries do not, which is natural given how the inquiries are more concerned with gathering facts and writing a report for future policymaking rather than account for stakeholder opinions.

Table 1 — The four governmental inquiries since 2000.

| Title of inquiry report                                      | Year | Background for the initiation                                                                                                                                                                                                                                                                                                                                 | Number of statements |
|---------------------------------------------------------------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Action Plan for Phosphorus Recycling from Sewage (SEPA 2002) | 2002 | Parly a result of the preceding ban imposed by the Federation of Swedish Farmers against any application of sewage sludge to Swedish agricultural land.                                                                                                                                                                                                                                                                  | 45                   |
| Updated Action Plan for Phosphorus Recycling from Sewage (SEPA 2010) | 2010 | Launched to investigate: 1) why the limit values suggested by the 2002 inquiry were never implemented and 2) to map potential new technologies for phosphorus extraction.                                                                                                                                                                                                                                                                   | 50                   |
| Sustainable Recovery of Phosphorus (SEPA 2013)               | 2013 | In comparison to the previous inquiries, this inquiry aimed to add many types of waste fractions. Hence, sewage sludge was herein presented as one out of many potential sources of phosphorus.                                                                                                                                                                                                                                                                                   | 88                   |
| Sustainable Sludge Management (Government Offices of Sweden 2020) | 2020 | Launched to outline how all land application of sewage sludge could be banned and replaced by extraction through other means. However, it delivered two alternatives, one allowing agricultural use and the other one not.                                                                                                                                                                                                   | 289                  |
3.2. Method of analysis

In our assessment of the material, we traced how the interactions of phosphorus (or nutrients in general) and social actors were articulated.

We analyzed the statements of opinions in sets dependent of which actor category that had submitted them. We started with municipalities, continued with government authorities, and so on, until all the statements by all the actors were thoroughly assessed. The texts were read and occurrences naming phosphorus, or the more generic category nutrients, where carefully noted. The third step of the process was to note what the stakeholders connected phosphorus to and how. Here, it is important to note, that since each stakeholder could relate phosphorus in various ways throughout their statement of opinion, we included both overlaps and differences found in that actor’s responses in our analysis, as well as overlaps and differences with other stakeholders. We found the differences and overlaps that changed over time to be of particular interest. The fourth step was to inductively group these occurrences thematically according to how they were similar, i.e. what they related phosphorus to, and how.

The process was iterative as we continued with each new set of stakeholders. After each close reading and analytical iteration of a new set of statement of opinions, we revisited, reformulated and sharpened the thematic groups, and this process was repeated until all the material had been analyzed. Our analytical procedure was similar to Rapley’s (2011) pragmatic sketch on how qualitative data analyses commonly are performed, see also fig. 1, for an overview.

Our analytical method combines both deductive and inductive elements, where the deductive part was guided by how we wanted to explore what chemo-social relations could be and how this in turn could help to understand the difficulties to re-circulate nutrients in sewage sludge. The formulation of these relations was however done inductively without preset criteria. Instead, they emerged as the different occurrences were grouped together. Our approach resembles what Timmermans and Tavory (2012) calls abductive analysis, an analytical method that “involves a recursive process of double-fitting data and theories” (Timmermans and Tavory, 2012, p. 179). Their main argument is that the inductive approach rarely generates novel theoretical insights, and that the analytical tension between empirical data and theory is instead essential. For our analytical efforts in this article, this insight was pivotal in order to cast new light on a long-term conflict of phosphorus circulation.

Furthermore and accordingly, our analytical efforts were not interested in mapping how many times a certain relation was mentioned. Rather, the various articulated relations were grouped iteratively into larger themes, to show how some of them reoccurred among different actors and how different actors’ articulations overlapped. More precisely, this meant that we in turn: 1) detected where phosphorus or nutrients in general (of which phosphorus is one) were articulated in the texts, 2) analyzed what human-phosphorus relations were made explicit, and 3) clustered the articulations thematically.

4. Results

In our analysis of the material, we categorized five main chemo-social relations to illustrate how eco-cyclical and circular economy thinking interrelate in the case of sewage sludge phosphorus. These five were: 1) a metabolic relation, in which phosphorus connects food consumption and production, 2) a purity relation, in which phosphorus takes part in wastewater treatment processes, 3) a nutritional relation, in which phosphorus is lumped together with other nutrients and sources, 4) a market relation, in which phosphorus is a potential competitor in global trade, and 5) a geopolitical relation, in which phosphorus invokes acts of solidarity and calls for national self-sufficiency. These are further described in the following sections (see also Table 2 for an overview).

![Fig. 1. Scheme for the iterative process to elicit chemo-social relations.](image-url)

Table 2
Overview of the five chemo-social relations and changes over time.

| Relation     | Characteristics                                                                 | Changes over time                                                                 |
|--------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Metabolic    | • Phosphorus in human excrements and urine should be returned to agriculture in natural eco-cycles. | • Initially, source-separation was defended to achieve a metabolic phosphorus circulation. |
|              | • Reuse of phosphorus should unite agricultural production and consumption, as well as the rural and the urban. | • Later, alternative pathways to sewage sludge phosphorus being returned to agriculture, were excluded. |
|              | • Phosphorus is a threat because of its eutrophication capacities.               |                                                                                  |
|              | • Human ejected phosphorus is mixed with other substances and phosphorus from other sources, which pollutes the eco-cycle |                                                                                  |
| Purity       |                                                                                  |                                                                                  |
| Nutritional  | • Phosphorus is related to other nutrients like nitrogen and potassium           | • Limit values for sewage sludge suggested as a means to distinguish the pure from the impure phosphorus. |
|              | • Sewage sludge is related to other sources of phosphorus like mining and food waste | • This is replaced with a desire to extract phosphorus and cut the link to sewage infrastructure. |
| Market       | • Phosphorus from sewage sludge is regarded as a saleable product                | • A continuous struggle between an encompassing view on all nutrients in sewage sludge and a view solely focused on extracting phosphorus from various sources |
|              | • Aims at larger markets than the local society                                 | • A shift of focus from a strife towards a natural eco-cycle to circulation based on profit |
| Geopolitical | • Phosphorus is a unevenly endowed globally, with major deposits outside the EU  | • Recirculation is motivated by global solidarity and regional self-subsistence. |
|              | • The covid-19 pandemic is a reminder of national vulnerability                  | • This is later complemented with preparedness as a national goal. |

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4.1. A metabolic relation

The first chemo-social relation we discerned in the material was a metabolic relation. This relation emphasized the metabolic benefits of returning sewage sludge to soils and further food production. Such cyclical flows of phosphorus between food, humans and soils, were by the stakeholders described as "natural" in the sense that they comply with pre-industrial phosphorus cycles that existed before the trifold human intervention of industrial farming, mining of phosphate bedrock and urban waste-water management solutions.

4.1.1. Connecting production and consumption while rejecting alternative pathways

Metabolic ideals were notable in stakeholder arguments of how phosphorus should be returned to farmlands, and the stakeholders stressed the importance of (re-)creating chemo-social connections between the countryside and urban areas in sustainable cycles (Cb 2002, la 2013 and 2020, lc 2002 and 2020, Pe 2020). The configuration of sewage sludge management, so that it closes the loop between agricultural production and human consumption, entails a metabolic norm emphasizing that phosphorus should be returned to productive agricultural land (Mc 2013, Cb 2002). The spreading of sludge to non-agricultural land should however not be regarded as an eco-cycle (Md 2010).

The normative metabolic relation implied a practical dilemma for some Swedish municipalities where agricultural application is not feasible (cf. Mc 2020, Md 2020, Mf 2020, la 2020). The forest abundant municipality of Kristinehamn, uses sludge for landfill reclamation and considered sludge-incineration since they lack agricultural areas where sludge could be spread (Md 2013). Ever since the 2002 inquiry, Kristinehamn had urged in vain for a reconsideration of the suggested ban on landfilling of sludge (Mc 2002). Rather, Kristinehamn regarded the “ban all sewage sludge land application”-approach of the 2020 inquiry as the last nail in their sludge solution-coffin and claimed that this approach would strike hard towards small municipalities in non-agricultural regions (Mf 2020). Other municipalities such as Enköping were also worried that a focus on the recycling of phosphorus to agriculture would result in increased incineration in areas where agricultural use was not feasible (Ma 2020). Even municipalities in the agriculturally abundant Swedish South expressed fear that too much sludge-incineration would undermine other usages of sewage sludge like for example as a substrate to produce biogas or for the utilization of other nutrients (Mb 2020).

Ragn-Sells stressed that banning all land application of sewage sludge, as suggested by the government in the 2020 inquiry, would destroy fully functioning circular solutions. Their suggested and incineration-dependent, technology should only be used for the two-thirds of sludge which was used for land reclamation, so that all phosphorus would eventually be returned to food production. According to the metabolic relation, this is where it naturally belongs (Cb 2020).

4.1.2. From source-separation systems to separation of the issue

The metabolic relation is especially prominent in the earlier inquiries, where stakeholders strongly advocate their support for source-separating toilet systems that separate urine from feces and disconnect household effluents from industries and businesses dit-to. Even the Swedish Chemical Agency, otherwise reluctant to use sewage sludge as fertilizer, stated that it is necessary to divert other sources than household wastewater from the sewage sludge in order to use it as fertilizer (Pc 2002).

While some stakeholders like the Swedish University of Agricultural Sciences (Ua 2002, 2010 and 2013) and the Federation of Swedish Farmers (Ib 2002, 2010, 2013 and 2020), held on to such a standpoint over several inquiries, others’ support for source-separation systems faded over time (cf. Pc 2002 and 2013, Eb 2002 and 2020). The Swedish Natural Conservation Association, Sweden’s largest environmental NGO, were positive towards such systems in their response to the first inquiry, but started to question the possibility to implement them over time (Ea 2002, 2010, 2013 and 2020).

The hesitancy towards source-separating systems began already in 2002 when the Swedish Natural Conservation Association stated that the debate should be broken down into two disparate questions: 1) how to dispose of sewage sludge and 2) how to supply agriculture with nutrients (Ea 2002). They argued that the answer of the former could, but must not, be the solution to the latter. The disconnect between these two questions increased in their later statements of opinion. In their answer to the inquiry from 2013, they stated that technologies to extract phosphorus from sludge should be regarded as a complementing alternative (Ea 2013). In 2020, source-separating systems were not mentioned at all. Instead, they explicitly favored technologies that extract and circulate phosphorus from the sludge back to agriculture rather than solutions based on sludge circulation (Ea 2020).

4.2. A purity relation

However “natural” the metabolic relation might feel, the phosphorus found in sewage sludge is not solely constituted of human excrement. There are other substances such as detergents and food waste in there as well. Such non-digestive inlets of phosphorus, which are unavoidable given how household laundry for example is an inherent part of municipal water infrastructures, disrupt the metabolic cycles of phosphorus. Rather than regarding wastewater as a deposit from which nutrients can be recycled, wastewater treatment facilities have thus so far focused on the cleaning of water to counteract eutrophication. One of the cleaning steps in such facilities is the flocculation of phosphorus using iron molecules (or other coagulants). Such efforts to clean wastewater from pollutants is part of a chemo-social relation between humans and phosphorus based on a strive towards increased purity. In this relation, the order is reversed: rather than aiming at metabolic circulation of phosphorus for its chemical advantages, it wishes to divert phosphorus away from the wastewater because of its disadvantageous capacities.

4.2.1. Disturbed phosphorus cycles

There are several phosphoric flows that disturb the idealized phosphoric cycles sought after in the metabolic relation. The city of Göteborg argued in 2002 that phosphates in detergents used for laundry should not be regarded as a source of phosphorus to circulate, since this was implied in a fundamentally different relation than the natural, metabolic one described above (Mc 2002). Göteborg instead articulated a relation to phosphorus based on purity, in which phosphate molecules have been added in detergents to clean things for us (Mc 2002), and therefore should be stabilized or removed rather than recycled to agriculture. A perplexing feature of this relation is that these phosphates acted as an obfuscating and polluting factor when found in the sludge, since they added a non-human source of phosphorus that is not perceived as natural.

Food waste, another phosphorus source, evoked opposite reactions from stakeholders in the material. The Federation of Swedish Farmers wondered why shredded food from waste grinders were not considered as a source of phosphorus (Ib 2002), and similarly Eslöv, a small municipality in the agriculturally abundant South where many large food companies operate, wrote that food industry waste is the main contributor of phosphorus to their municipal wastewater streams (Mb 2002). The Federation of Swedish Farmers
also questioned whether phosphorus in the sludge is useful as fertilizer, since the flocculation processes to stabilize phosphorus at the wastewater treatment plant impede the release of phosphorus into water recipients and agricultural soils as well (Ib 2002).

These stakeholders were concerned with how streams of phosphorus from food waste and detergents transform sewage into a mixed-up phosphoric waste stream, and they highlighted frictions that stem from when different phosphoric relations are mashed up into one by the wastewater management infrastructure.

4.2.2. Limit values
To achieve higher acceptance and trust in sewage sludge as fertilizer, the inquiries from 2002, 2010 and 2013 suggested stricter limit values to ensure that sewage sludge was clean enough. In response to this, the municipality of Eslov asked “what should be done with the sewage sludge which does not pass the needle’s eye?” (Mb 2010). Three years later, the same municipality worried that stricter limits would decrease their amounts of sludge suitable for agriculture from 80% to 30% (Mb 2013). Concerns regarding how stricter limit values would increase the amounts of incinerated sludge rather than increase phosphorus recycling, were voiced by other actors (Mc 2013, Me 2013). This reflected how some municipalities had more highly polluted sludge and would be further affected by sharpened limit values than others. Not all stakeholders were convinced that updating the sanitation infrastructure to achieve cleaner sludge would help the utilization of sludge further. In 2002, wastewater treatment plant operators for example stated skepticism towards investment in source-separating systems as well as incremental improvements of the current system to enable utilization of sewage sludge (cf. Wc 2002). Instead, they promoted alternative technologies to extract the phosphorus.

Instead of implementing stricter limit values or reconstructing the wastewater infrastructure, the Swedish Food Agency stressed that the connection between phosphorus and the wastewater infrastructure must be broken (Pg 2002), and the Swedish board of Agriculture stated that other means than the spreading of sludge on agricultural land must be developed (Pb 2010). The Swedish Board for Agriculture later developed this further (Pb 2013), saying that “sewage sludge is indeed different from other sources of phosphorus as it contains or could contain the broad spectrum of chemicals found in society.” Instead of considering phosphorus recycling as part of the wastewater infrastructure, some actors like the recycling company Ragn-Sells wanted to circumvent the sensitive issue of using sludge as a whole and instead focus on the circulation of phosphorus and other nutrients (Cb 2002). Later, in 2020, they stressed that phosphorus of sewage sludge origin should not be pre-judged by its relation to sewage infrastructure but rather evaluated by its individual qualities and harmonized with other sources of phosphorus (Cb 2020).

4.3. A nutritional relation
In statements of opinions to all of the inquiries, stakeholders stressed that a singular focus on phosphorus was too limited. Instead, they suggested that phosphorus should be regarded as one of many other nutrients in sewage sludge.

4.3.1. Phosphorus and other nutrients
In the 2002 inquiry, a group of stakeholders appreciated the inquiry’s departure away from the narrow focus on phosphorus demanded by the government (Mb 2002, Md 2002, Me 2002, Mf 2002, Cb 2002). Some twenty years later, in 2020, Kristinehann wrote that the emphasis should be to return all nutrients found in sludge rather than focus on technologies capable of extracting phosphorus alone (Mf 2020). They were supported by the Organic Farmers (Ia 2020), who feared that the sole focus on phosphorus would lead towards suboptimal technological solutions. Helsingborg, one of the largest towns in Southern Sweden, pointed at possible infrastructural lock-ins if sludge incineration for phosphorus extraction would be implemented at a larger scale, as this would result in a drift away from local eco-cycles towards centralized phosphorus-recovery (Md 2020). The Federation of Swedish Farmers were persistently concerned with how incineration would lead to losses of nitrogen and humus and referred to phosphorus and other nutrients (or even naming them) throughout all of their statements of opinion, as they feared that the exclusion of some vital nutrients would result in a loss of important synergies (Ib 2002, 2013; see also Ia 2013, 2020).

Still, and even though most actors underscored that all nutrients are important, it is only phosphorus who gets set recovery quotas in the inquiries, thus shining brighter than the other sewage sludge substances. Despite early warnings that goals for phosphorus-recycling might lead to suboptimal solutions (Mc 2002), the suggested phosphorus-quotas were continuously quantified and increased over time by the inquiries, implying a temporal change where phosphorus recovery became increasingly important over time. Similarly, a company could be harshly criticized for only recovering phosphorus in 2002 (Ca 2002), whereas farmers’ advocacy of the recycling of other nutrients in later inquiries (Ia 2013, Ib 2020) was not given much attention.

4.3.2. Competing sources of phosphorus
The nutritional relation to phosphorus also enabled stakeholders to compare sewage sludge to other sources of phosphorus found in society. Some actors strongly advocated that all fertilizers should be regulated using a common framework, in which sewage sludge was but one of many sources of phosphorus (Md 2013, Cb 2002, 2020, Ca 2020). The Swedish University of Agricultural Sciences stated that limit values should be uniformly set for all fertilizers as some of them contain similar pollutants as sewage sludge without being regulated (Ua 2020). The County Administrative Board of Dalarna, a forest abundant Swedish county where many municipalities use sewage sludge to produce soil, argued that it made no sense to restrict the use of sludge to agriculture if this led to imports of inorganic fertilizers for the production of garden soil (Pd 2013).

Two Swedish municipalities claimed that lumping together different fertilizers under the same regulation was unnecessary (Md 2013, Mf 2013, 2020). From their point of view, sewage sludge and other organic fertilizers were different beasts. Additionally, the importance of sewage sludge as a phosphorus source was played down by the County Administrative Board of Dalarna through comparisons with phosphorus rich tailings from iron ore mining which could be used for extraction (Pd 2002).

4.4. A market relation
The disposal of sewage sludge has traditionally been driven by cost minimization, but if sewage sludge is morphed into a fertilizer product due to its content of phosphorus and other nutrients, the extraction of phosphorus from sludge might change to a profit-driven activity. Such a market relation between humans and phosphorus, transforms phosphorus from being an excess to a product and implies that it could generate profits.

4.4.1. Extraction of phosphorus from sludge
Over time, the extraction of phosphorus from sludge, as suggested by stakeholders in our material, could result in phosphorus products that could transgress national borders and extend the cyclical capacities to the exchanges of global markets.
The first suggestions of this are found already in the first inquiry of 2002, when the chemical company Kemira and the recycling company Ragn-Sells, suggested that sludge incineration could be a solution to extract phosphorus and overcome the erosion of trust that led to the 2002 inquiry (Ca and Cb 2002). The previously existing sewage sludge partnership had collapsed in a blame game (Ca 2002, Ib 2002, Mc 2002), in which the food industry was accused of being the main obstacle against nutrient recycling (Cb 2002) while the Swedish Food Federation in turn referred to the need of consumers acceptance which simply was not there (Ic 2002). Instead, the Swedish Food Federation saw the wastewater operators as primarily responsible for the handling of sewage sludge and emphasized how they themselves should preferably lead the way on this issue (Ic 2002). However, Ragn-Sells and Kemira were concerned that extraction of phosphorus (from the incinerated sludge-ashes) would not be competitive (Ca and Cb 2002). Spreading of sludge was a cheap technology, and a shift towards combustion/extraction was dependent on consumer, farmer and industry demand (Ca 2002).

Ten years later, Ragn-Sells wrote that the 2013 inquiry had not fully acknowledged their recently developed technology for incineration and phosphorus recovery. They concluded that all incineration of sewage sludge should require phosphorus-extraction (Cb 2013). A resource-efficient circulation, according to them, demanded the return of phosphorus without exposing others to harmful substances. This would be solved, they argued, if the sludge was burned to allow for phosphorus extraction. Sewage sludge was in this way suggested as a contender of inorganic fertilizers, and phosphorus could be produced, packaged and sold as a commodity on (possibly) international markets (Cb 2013).

In the latest inquiry from 2020, Ragn-Sells further stressed the market relation between humans and phosphorus, and they had moved even further along the lines of marketization of phosphorus by means of combustion/extraction-methods. They stated that incineration and recovery was the best option as it fit the fertilizer industry and produced a clean product (Cb 2020). Kemira agreed, as such a process resulted in calcium-phosphate and phosphoric acids that were already well-established on the international market (Ca 2020). Ragn-Sells was however still concerned over the salability of agricultural produce fertilized with phosphorus extracted from sewage sludge (Cb 2020). Other stakeholders were also hesitant about the economic viability of extracted phosphorus as fertilizer and particularly mentioned high production cost and uncertain market demand (Ja 2020, Pb 2020, Pe 2020).

4.4.2. Other possible market outlets

Amongst another group of stakeholders, there was a completely reverse trend away from phosphorus extraction towards favouring local eco-cycling. The shift towards a more positive position on the spreading of sewage sludge on agricultural land was for example discernable amongst the Swedish Food Federation (Ic 2002 and 2020), Stockholm Vatten (Wc 2002 and 2013) and the Käppala wastewater treatment plant (Wb 2002 and 2020) and should be understood as a result of the increasingly improved cooperation between the wastewater treatment plant operators and the agricultural sector. Key to this improvement was a certification system that led to sewage sludge of good quality becoming highly demanded in some areas.

Building a market relation that enabled economic exchange of phosphorus in sewage sludge was thus dependent on the purity relation. The Federation of Swedish Farmers described the complications of using phosphorus of sewage sludge-origin, when they wrote that the upside of sewage sludge land application was that it was free of charge. The downside, however, was that agricultural products fertilized with sludge were not bought by all food industries (Ib 2020).

4.5. A geopolitical relation

Globally, phosphorus is an unevenly endowed mineral: it is abundant in some regions while scarce in others. For this reason, some actors strongly advocate nutrient recycling to secure the domestic supply of phosphorus. The geopolitical relation between humans and phosphorus is accentuated by how phosphorus is an important player in actor positions regarding international trade and matters of food security.

In 2002, the Federation of Swedish Farmers stressed that even if Swedish consumption of mined phosphorus is among the lowest in the EU, thus only marginally affecting global supply chains and international trade patterns, recycled phosphorus could be exported from Sweden and replace non-renewable phosphorus globally (Ib 2002). This, they wrote in a line of argument driven by ethics and economic profit seemingly combined, was a reason why Sweden and the EU should recycle their waste flows of phosphorus to aid poorer countries (Ib 2002). In similar veins, The Public Health Agency found a lack of an international perspective in the 2002 inquiry highlighting a North-South divide and the potential risk that richer countries might exploit poorer ones (Ph 2002). Swedish Water, the industry organization for wastewater treatment plants, wrote in 2013 that every additional amount of sewage sludge applied to agriculture in Sweden reduced the global addition of cadmium. They stated that inorganic fertilizers on the global market contain much higher levels of that particular heavy metal (Id 2013). Making sewage sludge a marketable product could in this way be regarded as a chemo-social act of solidarity. The geopolitical relation between humans and phosphorus is implied in how reduced consumption of high-quality minerals in wealthier countries could prevent poorer parts of the world from being reliant on mining of phosphate rock of lower quality.

There are also geopolitical chemo-social relations that go beyond acts of solidarity. Companies like Kemira and Ragn-Sells stated that the supply of phosphorus is critical in the EU and that the dependency on renewable sources of phosphorus was important since a shortage implied a threat to the union’s food security (Ca and Cb 2020). These private actors stressed the geopolitical relation by referring to how phosphorus was an irreplaceable fertilizer in modern agriculture, adding that phosphorus was mined in a few and geopolitically crucial countries with large deposits.

It is not only through the Swedish membership in the EU that phosphorus becomes a geopolitical concern. The global was connected to the local conditions for food production when the municipality of Eslov wrote that the Covid-19 pandemic should be a wake-up call to increase national self-sufficiency. In doing so, they highlighted phosphorus’ importance to Swedish policymaking by stressing how phosphorus supply was vital for Swedish food production since there were no domestic deposits of suitable bedrock (Mb 2020). Swedish Water, who had previously highlighted solidarity with regards to cadmium contamination, stressed the necessity to close nutrient-loops between cities and agricultural production as part of a crisis preparedness. They argued that the current pandemic brought forward the importance of a national circular economy (Id 2020). The dependency on phosphorus as made available by international trade, is articulated as a kind of threat rather than an ensuring supply in their statement of opinion.

5. Discussion

In all of the five chemo-social relations, phosphorus is not just regarded as a matter of fact, a mere substance in sewage sludge, but a matter of concern (Latour 2004). By this is meant that the stakeholder’s articulate phosphorus in ways that makes a difference in political decision making regarding the circular economy. While the previous section of this paper gave an account of which
chemo-social relations that can be distinguished in our material and how these have changed in the Swedish debate during the last 20 years, the following section focuses on how these relations make a difference in policymaking regarding circulation of phosphorus.

In our material, we can see that the stakeholder support for source-separation systems and local eco-cycles fades over time and is mostly articulated in statements of opinions to the first of the four inquiries. Moreover, we see a shift of emphasis towards large-scale profit-driven circulation of extracted phosphorus from incinerated sludge, which is a similar trend to the one found by Johansson and Henrikkson (2020). However, this focal transition is unevenly emphasized among the stakeholders; some are more positive towards it, and thus articulate it more extensively, than others. Hence, the results of this study have implications for studies on particular technologies, like source-separation and phosphorus recovery, and the difficulties to implement these (compare McConville et al., 2017 and Nedelcu et al., 2019).

The most articulated voices in favor of extraction come from an actor coalition consisting of the Swedish Chemical Agency, the Swedish Society for Nature Conservation, and the private companies who promote their extractive solutions to this aim. In this way, our findings comply with Niskanen et al. (2020), who distinguish a national consensus between environmental movements and industry enabled through their shared support of an increasingly circular economy. Furthermore, in line with Johansson and Henrikkson (2020), we would argue that this shift of emphasis is typical for the transition from eco-cyclical thinking towards a circular economy ditho. The shift implies a move towards the elimination of potential contaminants, a particularization of a single, marketable substance (phosphorus rather than the amalgamated sludge in our case), and an extractivist logic in which substances are predominantly mined rather than circulated as a whole (see Steiner and Geissler, 2018). However, as we can see in our material, stakeholders involved in chemo-social relations with phosphorus that do not translate easily into this circular economy paradigm, obstruct and resist this development.

For example, there is a tension between those who favor extraction as a tool for phosphorus circulation adhering to the market relation with a focus on creating a product capable of replacing inorganic fertilizers on the global market (see de Boer et al., 2018), and the proponents of the nutritional relation who stress the inclusion of all sludge-related nutrients (and not only phosphorus). Together, these two stakeholder coalitions were so significant that the inquiry from 2020 was unable to suggest a complete ban on land use and a single way forward. Instead, the inquiry introduced a second option allowing sewage sludge spreading on agricultural soil against the intention of the government. The ways that the market relation collide with the metabolic and nutritional relations in this way is part of the reason why political decisions for increased phosphorus are not easily achievable.

Another dimension in which tensions between the different relations are articulated is seen in how the metabolic relation, where phosphorus is destined for agriculture, was so strongly advocated by stakeholders, the authors of the inquiries, and the government that it overshadowed other relations and practices. For example, sludge destined for agricultural use amounts only to a third of the total annual amounts of sewage sludge in Sweden, while the rest finds other outlets such as soil remediation and topsoil solutions for landfills (Eurostat, 2018). Thus, the metabolic relation, regardless of how strongly advocated it might be by certain actors, is not an option for stakeholders that do not have access to agricultural application. These stakeholders, on the other hand, found themselves neglected in the inquiries. Their purity relation to phosphorus and their continuous need to handle sewage sludge, and their needs to treat wastewater and separate phosphorus and other substances, still required action. They were thus caught between chemo-social relations that could not easily be joined together. The suggested ban of all sludge land application, even if allowing for agricultural use, is of no use to a municipality without farmlands that cannot easily get involved in a metabolic relation reliant on local eco-cycles.

Another kind of tension between different chemo-social relations can be seen in how sewage sludge is an amalgamated mess of substances that resists easy circulation. Phosphorus, as an element, can travel between countries through food items, mineral fertilizers and detergents (Linderholm et al., 2012). Sewage sludge on the other hand, cannot easily be re-circulated to other sites of utilization (Jedelhauser and Binder, 2018). Finding wider markets to enable global circulation of nutrients found in sewage sludge thus require an extracted product such as phosphorus, which is emphasized by the food industry and recycling companies alike. The redistribution of phosphorus to regions in short supply could overlap with the desire to make it marketable. On the other hand, the unequal endowment of phosphorus is highlighted by wastewater treatment plants and municipalities, who urge for national self-sufficiency of nutrients to decrease the vulnerability to international crises due to for example restricted phosphorus trade.

For all of the above-mentioned reasons and given the intricate and simultaneous ways that humans and phosphorus interact, building idealized loops based on closed economies and frictionless circulation of materials becomes enormously difficult (cf. Banquet et al., 2020). On the other hand, so does imitating a global fertilizer market. When policymakers want to decide on one particular way to circulate phosphorus, they must be prepared for resistance from actors entangled in chemo-social relations that are not aligned with their visions (cf. Ritzén and Ölundh Sandström, 2017). Hence, the various ways in which a circular economy can be implemented is a political issue in itself (cf. Valenzuela and Böhm, 2017), and a choice based on values and certain perspectives of the world made explicit through some, but not other chemo-social relations.

Lastly, we want to stress that research on chemo-social relations in sewage sludge management is a rewarding way to understand the difficulties to achieve increased recycling. Previous research on circular sewage sludge management has highlighted the importance to include stakeholders’ perspectives, values and norms, rather than a narrow focus on technical details (e.g. Harder et al., 2019; Mason-Renton et al., 2019; Shaddeel et al., 2019). In line with this, our study can inspire to similar studies and be a point of comparison when investigating other countries and regions.

6. Conclusion

In this article, we have shown how phosphorus is involved by stakeholders in chemo-social relations that affect the policy process of sewage sludge management in Sweden in different ways.

Wastewater treatment operators and farmers are involved in a metabolic relation to motivate local, cyclical flows of sewage sludge to farmlands, in ways that connect the urban and the rural, consumption and production. This metabolic relation poses challenges to local practices in municipalities far away from agricultural production. Private companies as well as other actors stress phosphorus’ geopolitical relations and put food security and safety reasons at the center of importance.

The recycling of phosphorus from sewage sludge, however, depends on many factors. Particularly, the sewage sludge origin challenges the use of phosphorus and puts pressure to establish a purity relation. Limit values are suggested by the inquirers and some stakeholders as a way to separate the good from the bad sludge, while farmers and universities advocate infrastructural reorgan-
zation in order to disconnect human excrements and urine from other sources. Yet, the Swedish Food Agency and recycling industries together with environmentalists promote the addition of incineration to the chain of sewage treatments. The extraction of phosphorus from the ashes of incinerated sludge, articulates an economic desire to turn waste into a product fit for recirculation on a global market. However, such a market relation does not come without obstacles. Phosphorus extraction is still seen as expensive and is questioned as it neglects the nutritional relation in its' disregard of other nutrients in sewage sludge.

The desire to recycle nutrients from sewage sludge has long suffered from how it narrowly distinguishes phosphorus as the main concern. Turning such a desire into national policy risks obscuring the many different relations that we have outlined in this paper and have benefits of their own. Highlighting the fact that the world is permeated with chemicals and thus intrinsically dependent on chemo-social relations, is important when solutions are suggested to isolate and extract phosphorus and other substances from heterogeneous sources where a multitude of other materials might be of interest. Refraining from too reductionist viewpoints is therefore needed, in future research on this and similar topics, as well as within the realm of political decision-making. Efforts that suggest too narrow solutions will ultimately reduce the variety of different existing relations and override local differences. Ultimately, any circular economy initiatives that are suggested but not informed by a thorough understanding of the contexts in which it is to be implemented, will face difficulties and run the risk of not reaching its full potential.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Appendix: List of stakeholders**

Here follows a list of the stakeholders whose statements of opinions have been included in this study. Statement of opinion is a stakeholder’s written response following an inquiry initiated by the government and constitutes a part of the public participatory process. Since 2000, four inquiries have been initiated regarding future sewage sludge management, all with a particular focus on phosphorus (see Table 1 for more detail). Table A1 shows the stakeholders and when they wrote their statements of opinions (marked with an x in the tables four right columns). The letters

| Table A1 | Included stakeholders in this study and when they stated their opinions. |
|---|---|---|---|---|
| **Ref** | **Stakeholder (name in Swedish)** | **2020** | **2013** | **2010** | **2002** |
| C | Private Companies | | | | |
| a | Remira Remi AB | x | | | |
| b | Ragn-Sells AB | x | x | x | x |
| I | Industry Organizations | | | | |
| a | Organic Farmers (Ekologiska Lantbrukarna) | x | x | x | x |
| b | Federation of Swedish Farmers (Lantbrukarnas Riksförbund) | x | x | x | x |
| c | The Swedish Food Federation (Livsmedelsföretagen) | x | | | |
| d | Swedish Water (Svernskt Vatten AB) | x | x | x | x |
| U | University | | | | |
| a | Swedish University of Agricultural Sciences (Sveriges lantbruksuniversitet) | x | x | x | x |
| M | Municipality | | | | |
| a | Eskilstuna | x | | | |
| b | Eslöv | x | x | x | x |
| c | Göteborg | x | x | x | x |
| d | Helsingborg | x | x | x | x |
| e | Kristianstad | x | x | | |
| f | Kristinehamn | x | x | x | x |
| g | Ludvika | x | x | x | x |
| h | Malmö | x | x | x | x |
| i | Västerås | x | x | x | x |
| E | Environmentalists | | | | |
| a | The Swedish Society for Nature Conservation (Naturkyddsföreningen) | x | x | x | x |
| b | An individual anti-sludge activist (Gunnar Lindgren) | x | x | | |
| W | Wastewater Treatment Plant Operators | | | | |
| a | Grytaa (Göteborg area) | x | | x | x |
| b | Käppala (Stockholm area) | x | x | | |
| c | Stockholm Vatten (Stockholm area) | x | x | x | x |
| P | Public Authorities | | | | |
| a | The Swedish National Board of Housing, Building and Planning (Boverket) | x | x | x | x |
| b | Swedish Board of Agriculture (Jordbruksverket) | x | x | x | x |
| c | Swedish Chemical Agency (Kemiakalinspektionen) | x | x | x | x |
| d | County Administrative Board of Dalarna (Länsstyrelsen i Dalarnas län) | x | x | x | x |
| e | County Administrative Board of Skåne (Länsstyrelsen i Skåne län) | x | x | x | x |
| f | County Administrative Board of Stockholm (Länsstyrelsen i Stockholm) | x | x | x | x |
| g | Swedish Food Agency (Livsmedelsverket) | x | x | x | x |
| h | Public Health Agency (Smittskyddsinstitutet [2002 and 2013] / Folkhälsomyndigheten [2020]) | x | x | x | x |
| i | National Board of Health and Welfare (Socialstyrelsen) | x | x | x | x |
| j | National Veterinary Institute (Statens veterinärmedicinska anstalt) | x | x | x | x |
