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Swedish sludge management at the crossroads

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Key messages

- **The recent sludge inquiry's alternative proposal to continue, rather than ban, sewage sludge reuse in agriculture was a welcome departure from its original mandate.**
- **Continued reuse under strict quality requirements would also incentivize for sustained upstream pollution-control work such as that under the REVAQ programme.**
- **Future policy development in this area should look for resource recovery options along the entire sanitation service chain, and broaden its scope beyond phosphorus to include incremental targets for recovering nitrogen, potassium and more.**
- **Such policy would stimulate the research and innovation necessary for a longer-term sustainability transformation of our sanitation systems: one that sees most of the nutrients and organic matter safely recovered and reused.**

On 17 January, a Swedish government inquiry delivered its report into options for managing (i.e. disposing of) the *c.* 200 000 tons (dry weight) of sewage sludge generated in Sweden every year (SOU 2020). The inquiry was charged with investigating how best to recover the plant nutrient phosphorus found in sludge, in light of a government ambition to completely ban the common practice of spreading sludge on farmland.

The inquiry, the latest attempt to settle a long-standing controversy over Swedish sludge management, proposed two options. The first was a complete ban on sludge reuse – as per the inquiry's original mandate; the second was to allow sludge spreading on farmland to continue, albeit under stricter quality requirements than at present, with five-yearly reviews. Both proposals include a target for larger treatment plants (serving more than 20 000 people) of recovering at least 60% of the phosphorus available in sludge within 12–15 years. Given that a complete ban on sludge reuse could be against European Union rules, it seems more likely the government will move forward with the second proposal.

This policy brief summarizes the background to the inquiry and its implications for the future of Swedish sludge management.

1 This policy brief builds on an earlier BONUS Return report on sludge management in three Baltic states (Olsson et al. 2018)

Sanitation and circular economy

The question of whether and how to reuse human excreta in farming has been answered in different ways across cultures and geographies. For example, it has been argued that the reuse of human excreta as a crop fertilizer is a key reason for the incredible longevity of the Chinese polity. In Europe, attitudes have shifted over the centuries, with

BOX 1. NUTRIENTS AND ENERGY AVAILABLE IN WASTEWATER AND SLUDGE

Nutrients

Nearly all the phosphorus in wastewater arriving at treatment plants is retained in sewage sludge in Sweden, due to the chemical precipitation of phosphates in modern wastewater treatment. However, while significant quantities of other nutrients are also found in wastewater, less than a quarter of the nitrogen and a very small part of potassium ends up in the sludge (see Table 1), instead being discharged with the treated wastewater (although *c.* 40% of nitrogen is returned to the atmosphere).

Table 1. Nutrients available in wastewater entering Swedish treatment plants annually, and how much is retained in sewage sludge

	Available in incoming wastewater	Available in post-treatment wastewater	Retained in sludge	
	t/yr	t/yr	t/yr	%
Nitrogen	41 049[a]	15 414[b]	9 259[c]	23%[d]
Phosphorus	5 546[a]	237[b]	5 486[c]	96%[d]
Potassium	14 852[e]	No data	899[e]	6%[d]

Based on (a) http://www.statistikdatabasen.scb.se/sq/74836, (b) http://www.statistikdatabasen.scb.se/sq/81586, (c) http://www.statistikdatabasen.scb.se/sq/74839 and http://www.statistikdatabasen.scb.se/sq/74837, data for 2016; (d) Nitrogen and potassium from nutrient quantity in sludge compared to incoming waste water; true retention % could be somewhat lower as some plants also receive sludge from on-site sanitation. Phosphorus retention based on the difference between incoming and outgoing water; (e) Potassium production in excreta and greywater from Vinnerås et al. (2006) and potassium concentration in sludge from Eriksson (2001), in addition to population connected to sewers and sludge production data for 2016 from http://www.statistikdatabasen.scb.se.

Table 2 compares the amounts of these three major nutrients applied to Swedish farmland every year in chemical fertilizer with the amounts available in incoming wastewater to treatment plants, the amounts retained in sludge, and the total amount in toilet wastewater (blackwater) generated in Sweden. Available nutrients in Swedish wastewater could potentially substitute for 22–56% of nitrogen, phosphorus and potassium applied in chemical fertilizers, while the sludge is mainly significant as a source of phosphorus. Source separation of blackwater enables the recovery of a large part of nutrients in sanitation systems but would mainly be an alternative for new housing development or in rural areas.

Table 2. Nutrients applied to Swedish farmland in chemical fertilizer, and how much could be substituted with nutrients potentially recovered from incoming wastewater and from sewage sludge

	Used in fertilizer (t/yr)[a]	In incoming wastewater (% of current fertilizer use)	In sludge (% of current fertilizer use)	In all blackwater (% of current fertilizer use)[b]
Nitrogen	186 000	22%	5%	25%
Phosphorus	13 100	42%	42%	39%
Potassium	26 500	56%	3%	48%

a Based on http://www.statistikdatabasen.scb.se/sq/74842, data for 2015/16.

b All "potential" blackwater in Sweden, based on Jönsson (2019).

Energy

With anaerobic digestion, roughly half of the organic matter in sludge can be transformed to biogas, equivalent to 75 kWh/yr/person connected (although net energy recovered is somewhat lower in Sweden due to the need to heat the process, using 10–20 kWh/yr/person (Svenskt Vatten 2013). The organic matter left after digestion (c. 122 000 t/year, based on Jönsson 2019) is useful as a soil amendment together with the nutrients.

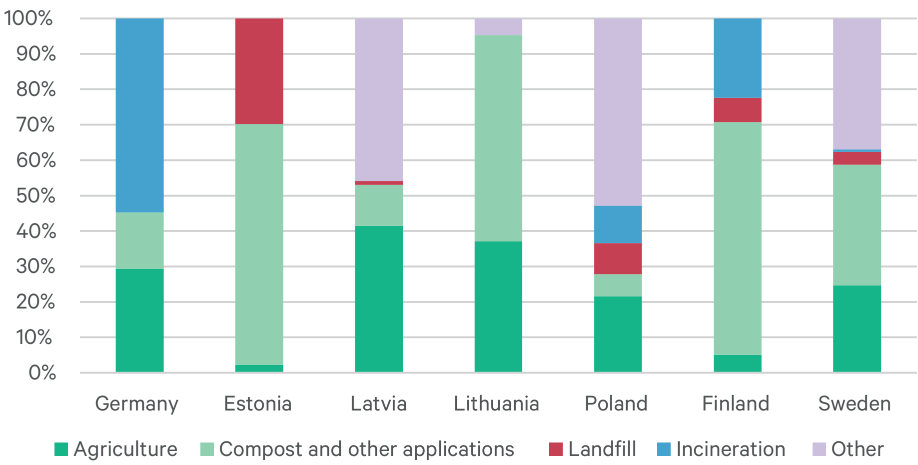
“humanure” sometimes valued highly, at other times spurned. Despite technological advances and increased knowledge in waste management, this ambivalence persists – although today discussion tends to focus on sewage sludge, not raw excreta.

Sewage sludge is a solid or semi-solid by-product from wastewater treatment. It mainly comprises organic matter and water, but also contains essential plant nutrients like phosphorus, nitrogen and potassium. As sludge can provide both renewable energy (e.g. in the form of biogas) and agricultural inputs, it is an interesting resource from the perspective of circular economy (see Box 1).

However, today’s centralized water-borne sanitation systems mix dilute excreta (“blackwater") with other household wastewater (“greywater”), and often with urban stormwater and commercial, industrial and institutional wastewater before treatment. This means that a wide range of substances can affect the quality of the final sludge, including contaminants such as heavy metals, medical residues, organic pollutants and, more recently, microplastics. Concern about these further complicates the question of whether, when and how sludge should be reused.

In Sweden, as in many other countries, agricultural sludge reuse has been debated for decades. Finding and implementing an approach that enables the return of the plant nutrients in the sludge to agricultural soils in a way that minimizes the perceived risks of contamination has proved to be highly challenging. The Swedish government inquiry into how a ban on sewage sludge application on farmland (and other types of sludge reuse) could be designed, was an attempt to finally settle the question.

Figure 1. Sewage sludge disposal methods in seven Baltic Sea countries in 2012



Note: "Compost and other applications" refers to "all application of sewage sludge after mixing with other organic material and compostation in parks, horticulture etc." Composted sludge applied to farmland is counted under “agriculture”.

Source: Data from http://appsso.eurostat.ec.europa.eu/nui/show.do?lang=en&dataset=env_ww_spd

Sludge management in the European Union

The EU produces around 10 million metric tons of sewage sludge every year, and how the sludge is managed has significant implications for the European environment. The various sludge management strategies used in different parts of the EU fall into a few main types, each with pros and cons. The most common is spreading sludge on farmland; almost half of the sewage sludge produced in the EU-27 is currently used for agricultural purposes. Slightly less than 25% is incinerated instead. The remainder is used for other purposes such as landscaping or sent to landfill.

Figure 1 shows the very different mix of methods used in seven countries of the Baltic Sea region in 2012. As can be seen, agricultural application is generally less popular than across the rest of the EU, with only Latvia deploying more than 40% in this way. Germany incinerated more than half of its sludge. Estonia, Lithuania and Finland relied heavily on "compost and other applications".[2]

Why member states have taken such different routes is not clear, although one likely factor is the lack of an effective EU policy framework on treatment of sewage sludge. The so-called Sludge Directive (86/278/EEC) is now more than 30 years old and has not been updated or revised, despite several discussions and consultation processes. As a consequence, regulatory differences between countries have emerged, for example limits on how much of heavy metals and other contaminants not covered by the directive can be in sludge used for agricultural purposes. Some countries such as the Netherlands have set very strict limits, which in practice makes incineration the only possible option. Among other things, this absence of a harmonized approach in the EU creates an obstacle to international knowledge sharing and technology exchange.

The end of sludge reuse in Sweden?

Shifting attitudes

In Sweden, agricultural reuse was part of the vision for sludge management in the first wave of construction of centralized wastewater treatment plants in the decades following World War II. It was seen as a low-cost solution to the problem of disposal that also brought benefits to farmers. Some even referred to sewage sludge as *smutsguldet*. It was not until the 1970s, however, that there were any public guidelines on how to hygienize the sewage sludge to reduce the risks from pathogens.

The 1970s and early 1980s also saw the start of intensive discussions on the potential risks related to other contaminants, especially heavy metals and organic micropollutants. Key actors such as the Swedish Farmers' Association (LRF), the Swedish Environmental Protection Agency (SEPA) the Swedish Water and Wastewater Association (SWWA) have held shifting positions on the safety of agricultural reuse and how it should be regulated.

A joint certification programme for wastewater treatment plants called REVAQ was launched in 2008 to allay concerns about reuse. REVAQ sets limits on key contaminants in sludge destined for reuse, and demands continuous reduction of these contaminants in the wastewater reaching treatment plants. LRF and SWWA currently recommend that only sludge from REVAQ-certified treatment plants that meets quality standards – about 45% of all sludge produced in Sweden – should be used on farmland.

The introduction of REVAQ has not, however, settled the controversies. For example, Swedish flour mills will not accept grain that has been fertilized with sewage sludge for fear of consumer backlash, and crops fertilized with sludge cannot be certified as organic (Svenskt Vatten 2013).

2 Note that data quality is poor as the 2012 Eurostat dataset is among the more complete but still completely lacks information on the situation in e.g. Denmark.

Furthermore, the current REVAQ guidelines do not cover emerging contaminants such as pharmaceuticals and microplastics. Despite this, the latest available statistics show that agricultural use of sludge has been increasing in recent years; at 34% of all sludge produced in Sweden it was the most common means of disposal in 2016. Another 27% of sludge was used in landscaping, and 22% to cover closed landfill sites (SEPA and SCB 2018, pp.19–20).

Incineration with phosphorus recovery: the best solution?

The most recent Swedish sludge inquiry, launched in the summer of 2018, was an attempt to balance the imperatives of, on the one hand, public health and environmental protection, and on the other resource efficiency in a circular economy (Government of Sweden 2018). It was mandated to recommend how to continue to recover one nutrient, phosphorus, from wastewater after phasing out direct reuse of sludge on farmland.

Currently the only option on the horizon for recovering and recycling phosphorus from sludge at scale – besides spreading it on farmland – is incineration, followed by recovery of the phosphorus from the ash using emerging technologies.

An outright ban on sludge reuse will force Swedish wastewater treatment utilities to either invest heavily in new technologies and logistical arrangements, or pay entrepreneurs for the equivalent services.

Among the Swedish voices in favour of incineration was an op-ed article announcing the launch of the inquiry in 2018, co-signed by then Environment Minister Karolina Skog, the Swedish waste management corporation Ragn-Sells, and others (Skog et al. 2018). It noted international interest in Ragn-Sells's patented new technology for recovering phosphorus from sludge ash.[3] Researchers at the Swedish University of Agricultural Sciences (SLU) linked to the development of the process have also offered strong academic support (Kirchmann et al. 2017).

Incineration can be seen as an effective means of purifying the sludge – both physically and symbolically. However, an outright ban on sludge reuse would force Swedish wastewater treatment utilities to either invest heavily in new technologies and logistical arrangements, or pay entrepreneurs for the equivalent services, most likely for incineration with extraction of phosphorus from the ash. Also, with the chief rationale for raising sludge quality gone, a move to incineration would almost certainly spell the end of systematic upstream anti-pollution work like that under REVAQ.

Even if the government pursues the inquiry's second proposal – allowing agricultural reuse of sludge, with higher quality requirements – incineration is likely to become a dominant practice. As the inquiry report highlights, given the uncertainty of being able to reach increasingly strict quality requirements and finding farms willing to receive the sludge, many utilities might simply opt to incinerate all sludge.

It will be important to maintain upstream work even when sludge is incinerated, however, to reduce pollution loads on the aquatic environments receiving the treated wastewater and to protect the biological processes in the treatment plant. There is no straightforward solution to this, but the inquiry proposes that SEPA be made responsible for coordinating and facilitating continued upstream preventive work, as well as overseeing quality standards for sludge reuse.

3 Ragn-Sells also has stakes in conventional sludge reuse, as a transport service provider for sludge from REVAQ-certified plants.

Too narrow focus on phosphorus?

Researchers as well as utility representatives have pointed out the limitations of focusing too exclusively on phosphorus recovery from sanitation systems. They instead argue for broadening the scope to include recovery targets for nitrogen, potassium, sulphur and organic matter, to ensure improved outcomes from a resource perspective as well as to avoid greenhouse gas emissions (Jönsson et al. 2018).

Jönsson (2019) elaborates these arguments further and emphasizes Sweden's current dependence on imported fertilizers, where a disruption in nitrogen supplies would imply 30–60% lower harvests from the first year, while a phosphorus shortage would significantly reduce yields only after 5–10 years due to the existing stocks in most soils. He also shows that nitrogen recycling has by far the highest climate change mitigation potential, partly from avoiding fossil-fueled nitrogen production and partly from avoiding N_2O emissions that occur in the process of removing nitrogen during wastewater treatment. Another argument concerns the global resource perspective, where there are currently lower economic reserves of potassium and natural gas (to synthesize nitrogen fertilizer) compared to phosphorus.

Having said this, it is important to note promising developments in synthesis of nitrogen fertilizer from renewable energy sources (Philibert 2017). These processes are still expensive but could become competitive in the near future given the declining costs of both renewable energy and electrolyzers, a key process component.

Looking beyond conventional sludge

With recovery requirements on other resources beyond phosphorus, it is more likely that treatment plant sludge would be reused, given the content of organic matter and other nutrients. However, sludge incineration with phosphorous extraction could still be an option, as most of the nitrogen and potassium in wastewater does not end up in the final sludge (see box 1).

Larger potential for nitrogen recovery lies in extracting it from water removed during sludge dewatering. Also, separating blackwater or urine from other wastewater streams at the source would allow almost complete resource recovery with minimal contamination by, for example, chemicals, heavy metals and microplastics, although pathogens and pharmaceuticals can still be an issue.

There are efficient methods for hygienization of blackwater, and the resulting product retains an attractive nutrient profile for agricultural use along with similar or even lower levels of contaminants (especially cadmium) per kg of phosphorus than are found in chemical fertilizers and manure (Jönsson and Vinnerås 2013). The H+ housing development in Helsingborg, Sweden, is demonstrating such methods on a larger scale; blackwater, greywater and organic waste are all collected, treated and reused separately (Kärrman et al. 2017). Another example of a promising source-separation approach is the urine-drying technology being developed at SLU (Prithvi 2019). This technology can be plugged into existing toilets, diverting and drying out the urine in a separate box, hence retaining the bulk of nutrients from our sanitation systems in a relatively clean fraction with low volume, without major retrofitting of pipes.

There are certainly financial, resource and environmental costs associated with recycling, not least related to transport. However, systems analyses seem to point towards significant reductions (25–40%) in greenhouse gas emissions, energy use and eutrophication if blackwater were separated and recycled, compared to conventional treatment and use of chemical fertilizers (Jönsson 2019).

Targets for recovery of resources beyond phosphorus would spur more research and development on upstream source-separation options as well as further development of resource recovery (especially of nitrogen) at wastewater treatment plants. A ban on sludge reuse would instead disincentivize the further development of these alternatives, as the inquiry interpreted "sludge" to encompass conventional sludge as well as source-separated blackwater and urine.

Policy considerations

A narrow focus on phosphorus and sludge will likely stifle the research and innovation necessary for a longer-term sustainability transformation of our sanitation systems.

The latest inquiry was the fourth major investigation by the Swedish government with a specific focus on phosphorus recovery from sanitation systems (in one case also including other organic waste streams) since 2002. The previous three did not result in new policy or regulations. Interestingly, all three emphasized the importance of broadening the scope beyond phosphorus to consider other nutrients, and the 2013 investigation proposed an initial target for recovery of nitrogen (SEPA 2013).

Fully or partially banning sludge reuse while recovering phosphorus would have the benefit of ending a long and contentious debate, and bringing much-needed clarity for utilities, farmers, food businesses and consumers.

But the narrow focus on only one resource, and a recovery target based on sludge as opposed to the sanitation system as a whole, will likely stifle the research and innovation necessary for a longer-term sustainability transformation of our sanitation systems: one that sees most of the nutrients and organic matter safely recovered and reused.

Allowing sludge reuse under stricter regulation, as in the inquiry's second proposal, would at least not close the door to innovative solutions for resource recovery beyond phosphorus in our sanitation systems. However, without explicit recovery targets for other nutrients than phosphorus, there will be little incentive to develop them.

Thus, while continued agricultural reuse with a phosphorus recovery target could seem a rational choice to solve the current sludge situation, it would be wise within this process to also include incremental recovery targets for other key nutrients in the sanitation system, stimulating further progress towards closed nutrient cycles. In this way, Sweden could stay in the frontline of sustainable sanitation development, as well as progressively reducing its dependence on imported fertilizers and also potentially cutting the greenhouse gas emissions linked to sanitation and fertilizer production.

In the end it is farmers, food businesses and consumers who will determine whether closing the loop between sanitation and agriculture will succeed in Sweden. The final step from recovery to reuse will depend on their trust in the system and the degree to which high-quality inputs can be delivered from sanitation systems. A clear, effective policy framework for safe resource recovery is long overdue.

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