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## The market for wastewater sludge (biosolids)

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**The Market for Wastewater Sludge (Biosolids)**

**Villy Søgård**

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**Villy Søgaard\***

## **Abstract**

Despite public approval from the Danish Environmental Protection Agency (Miljøstyrelsen), farmers have proven reluctant to accept wastewater sludge as a source of fertilizer. They are in fact still being paid for accepting it. Based on interviews with key stakeholders, a review of the literature, and theoretical reflections this paper analyses the barriers to the recycling of wastewater sludge.

**JEL classification:** Q13, Q15, Q21, Q24, Q25, Q53, Q55

**Keywords:** Sludge, recycling, wastewater treatment

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# **1. Introduction**

The treatment of wastewater in sewage treatment plants produces sludge. Sludge primarily consists of settleable solids sedimented in the primary clarifiers of the water treatment plant. It is often rich in nutrients (nitrogen, phosphorus, potassium, organic matter), but also contains a number of harmful substances that must be removed, diluted or processed to make it recyclable. Both the nutrients and pollutants emanate from the wastewater which comes as a mixture of domestic sewage, industrial effluents, run-off from pavements and roads, etc.

The problem background of the following analysis is that despite long-standing efforts to clean the sludge to make it recyclable, Danish farmers are still being paid for receiving it. The aim is to identify the main factors underpinning supply and demand for treated sludge in relation to agriculture. Understanding the barriers to demand is not only important from a business point of view. From a wider perspective, highlighting the barriers to recycling is a key element in the transition towards a circular economy.

Section 1 below briefly presents the method applied. Section 2 gives a brief overview of the issues pertaining to wastewater sludge – issues which are obviously related to its contents. Section 3 briefly considers the “the sludge process”, i.e. the generation, treatment and use or depositing of sludge. Against this backdrop Section 4 discusses the major supply and demand factors and touches upon their likely future evolution. Although the agricultural market for sludge absorbs the bulk of it, competing market opportunities are considered as well. Based on the presentations of Sections 2, 3 and 4, Section 5 goes on to combine the two sides of the market and discuss its likely evolution in light of foreign developments. Section 6 concludes.

## **2. Methodology**

Ideally, we would want to build a resource economic model, quantifying the relevant factors on both sides of the market and estimate their impact on quantities and prices. However, at this stage the available data does not allow us to do so. Instead, a rather more analytic approach has been adopted to identify the relevant determinants on both sides of the market and get an impression of their relative importance. Based on these as well as on experience from abroad the prospective development of the biosolids market is discussed.

As mentioned above, this analysis is based mainly on a qualitative approach. It basically consists of two elements, a literature review and a number of interviews with key informants. The literature review provided important information on 1) “the sludge process” (the generation, treatment and use or depositing of sludge), 2) relevant supply and demand factors, and 3) prospective developments in technology and markets. The interviews were very helpful in providing an insight into the relative importance of these factors and the key issues involved.

### 3. Wastewater sludge – content and issues

Wastewater includes all forms of water from housing, companies, run-off from pavements, etc. The so-called Wastewater Announcement (Spildevandsbekendtgørelsen, Retsinformation 2016) distinguishes several types of wastewater, depending on the source of it. At the most general level, three types of wastewater are distinguished:

- Domestic wastewater, typically including organic matter and nutrients such as organic nitrogen, ammonium and phosphorus.
- Roof and surface run-off from surfaces without any special pollution.
- Industrial or process wastewater, i.e., wastewater from businesses, industrial processes or polluted surfaces. This category of wastewater may contain a broad range of organic as well as inorganic pollutants. However, businesses discharging wastewater to public treatment facilities need to obtain a sewer connection permit, based on an application specifying expected levels of production, wastewater quantities and content of pollutants.

#### *Nutrients*

Eutrophication of the marine environment has been a major issue in a Danish context since the early 1980s (Nørring and Jørgensen, 2009). An overload of organic matter and nutrients may give rise to algal bloom, which in turn has caused oxygen depletion and, in a number of cases, massive fish kills in Danish waters. The first so-called Action Plan for the Aquatic Environment was passed in Parliament in 1987 in response to such an event<sup>1</sup>. The Action Plan introduced mandatory fertilizer plans to reduce the discharge of nitrogen from farms and initiated huge investments in sewage cleaning removing N and P. Since 2000, the European Water Framework Directive (WFD) (2000/60/EC) committed member states to ensure the status of all water bodies on a range of criteria by 2015. It is generally recognized, however, that the general limits imposed by the Action Plans have been insufficient to reach the original targets of the WFD.

#### *Heavy metals*

Heavy metals are another major source of pollution present in small quantities in sludge. In sufficient quantities they may give rise to serious health effects, such as abnormalities, cancer, cardiovascular diseases, diabetes, or other medical conditions. Other metals, such as engineered nanomaterials in consumer products, have also been found to adversely impact plants and micro-organisms in field experiments (Colman et al., 2013). In a review article, Chibuike and Obiora (2014) concluded: “plants growing on heavy metal polluted soils show a reduction in growth due to changes in their physiological and biochemical activities. This is especially true when the heavy metal involved does not play any beneficial role towards the growth and development of plants.” Fortunately, effective bioremediation is possible, e.g. by plant uptake (phytoextraction).

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<sup>1</sup> The summer of 1986 saw very serious problems of oxygen depletion in Kattegat. Dead lobsters were caught by fishermen in Gilleleje and displayed on TV. A 1987 consensus conference on the causes of this incident concluded that an excess discharge of nitrogen (mainly from agriculture) and phosphorus (mainly from sewers) was the main culprit.

### *Other xenobiotic substances*

A wide range of substances come under this category. Pharmaceutical or industrial compounds such as antibiotics, anticonvulsants, antidepressants, dioxins, estrogens, flame retardants, phthalates, phenol, etc. have been found in sewage sludge in international studies. It is obviously beyond the scope of the present paper to cover the plethora of potential hazards from exposure to all such substances. To name but one example, the gender-bending effects of man-made substances came to the fore in the early 2000s but had been detected in studies since the 1970s (Matthiesen and Gibbs 1998).

Since the establishment of the first sewers and the development of the invention of the activated sludge process by Edward Arden and William Lockett in the UK in 1914, the emergence, detection, regulation and gradual solving of sludge-related environmental problems has been an ongoing process. Unknown unknowns have become known unknowns (i.e., realized problems, catching the attention of at least a few scientists), they have been studied and gradually turned into “knowns” (well understood problems), and, in many cases, resolved. The literature on this topic clearly reflects that this process continues (see e.g. Clarke and Smith 2011; Eriksen et al. 2009; Chibuike and Obiora 2014). This process sets the scene for the central dilemma pertaining to sludge: how to recycle it without contaminating the environment.

## **4. The sludge process**

The treatment of sludge follows EU Directive 2008/98/EC on waste. Inspired by a life cycle philosophy, the Directive defines a waste hierarchy, aimed at minimizing quantities of waste while maximizing its utilization. The hierarchy ranges from the most favored option (prevention) to the least favored option (disposal).

- Prevention
- Reuse and preparation for reuse
- Recycling
- Energy recovery
- Disposal

Nearly all of the wastewater in Denmark is treated using mechanical treatment, biological treatment, nitrification, denitrification, and chemical treatment. Primary sludge consists of settleable solids sedimented in the primary clarifiers of the water treatment plant. Secondary sludge is sludge settled after biological/chemical cleaning. Secondary sludge may be applied to agricultural land, provided it meets the requirements laid down in the Sludge Announcement (Slambekendtgørelsen). This category of sludge is referred to as A-sludge, whereas B-sludge is sludge that fails to meet the limits defined for xenobiotic substances and must be composted. Finally, C-sludge contains too high concentrations of heavy metals and will typically be incinerated.

## 5. Markets for sludge

As mentioned in the Introduction, the aim of this report is to analyse the market for sludge. Despite its content of nutrients, the price of sludge to the farmer remains negative, i.e., farmers are being paid for receiving it. Against this background, we wish to analyse the factors determining prices of sludge, focusing in particular on the barriers to applying it to agricultural land.

**Table 1: The use of wastewater sludge (thousands of tons) 2008-2013**

*Source: Miljøstyrelsen (2015) Affaldsstatistikken, 2013, Tabel 3.16, p. 32*

	2008	2009	2011	2012	2013
Recycling in agriculture	80	75	81	80	80
Composting and other recycling	22	22	11	12	12
Incineration	29	31	38	38	35
Depositing	1	1	3	1	1
Total	133	130	133	131	129

As noted in *Affaldsstatistikken* (Waste Statistics), the percentage applied to agricultural land varies from 58 to 65 per cent of the total amount of sludge<sup>2</sup>. The publication observes that

“the level is below what it was in the 1990s, when up to 80 per cent was recycled on agricultural land. This decline should be seen in relation to the fact that in 1997 and 2000 the restrictions on the content of xenobiotic substances were tightened for agricultural applications of sludge. The tightening of regulations concerned a range of tar substances known as PAH’s, the wash active substances LAS, nonyphenols, NPE, as well as the plastic softener DEHP.”

(Miljøstyrelsen 2015, p. 32).

Note also that incineration has increased, possibly as a consequence of a reduced incineration levy.

It is questionable, however, whether or not it makes sense to talk of one single market for wastewater sludge, even for agriculture. On the supply side, the water treatment plants have to get rid of their sludge. Due to the role of transport costs, the market structure may perhaps be described

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<sup>2</sup> The amount of sludge applied was particularly low in 2009. In 2009 fertilizer prices were particularly low (cf. <http://www.indexmundi.com/commodities/?commodity=dap-fertilizer&months=120&currency=dkk> ) and so too was the total amount of sludge available.

as a special form of monopolistic competition in which suppliers do not have full control over supplies. As argued in Section 3, their choice is between more or less costly outlets, and to some extent this choice is dictated by the quality of sludge. Despite this it makes sense to consider the general factors affecting supply and demand (cf. Table 2 below).

Some of the wastewater companies sell their sludge directly to farmers, whereas others sell it through intermediaries. A 2014 study by DANVA showed substantial differences in the prices paid by the individual Water Treatment Works for having their sludge removed. The study included 16 wastewater companies, and the prices ranged from less than 1,000 to more than 3,000 DKK per ton of dry matter.

The two companies that paid the lowest prices handled the “sale” of sludge themselves and did not use intermediaries. These two companies also had their own storage facilities, which may well have improved their bargaining position vis-à-vis the farmers.

The content of dry matter turned out to be a major determinant of price, presumably due to its impact on transport costs.

**Table 2: Factors underpinning the supply and demand for sludge for agricultural purposes**

	Quantities in	
	Supply	Demand
<b>Increasing</b>	<ul style="list-style-type: none"> <li>• Number of households or companies</li> <li>• Quality of treatment</li> </ul>	<ul style="list-style-type: none"> <li>• Higher crop prices</li> <li>• Higher fertilizer prices/reduced supplies of other fertilizer inputs.</li> </ul>
	<ul style="list-style-type: none"> <li>• Industrial composition</li> <li>• Rainfall</li> </ul>	<ul style="list-style-type: none"> <li>• Nutrient content of sludge</li> <li>• Perception of sludge/Biosolids</li> </ul>
<b>Decreasing</b>	<ul style="list-style-type: none"> <li>• Higher transport costs</li> <li>• Alternative outlets for sludge</li> <li>• Alternative storage opportunities</li> <li>• Stricter environmental regulation</li> </ul>	<ul style="list-style-type: none"> <li>• Alternatives</li> <li>• Higher content of pollutants</li> <li>• Stricter environmental regulation</li> </ul>

Turning to the demand side, the demand for sludge is obviously a derived demand<sup>3</sup>. However, regulation interferes with the demand function. Thus the mandatory fertilizer plans impose a ceiling on the total amount of nutrients that can be applied to agricultural land in the form of waste products and animal manure. Below this ceiling a higher content of nutrients should make sludge more valuable, whereas the ceiling itself could have the opposite effect. As farmers tend to fertilize up to the ceiling, this is bound to have some impact on the demand for sludge.

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<sup>3</sup> *Derived demand* is the demand for factors of production (e.g. labour, capital or land) required to meet the demand for other final or intermediate goods.



As shown below, the demand for sludge could actually be *inversely* related to the content of nutrients in the sludge. Thus, reducing the nutrient content of the sludge need not reduce the price at which farmers are willing to accept it. In the DANVA study phosphorus content did not appear to be related to price. “As the data set is relatively small, one cannot rule out the possibility that e.g. phosphorus does have an effect. A possible effect may not be strong enough to generate a statistically significant result.” (Lassen & Ifversen, 2014, p. 46). Still, it goes without saying that if it becomes possible to extract and purify the nutrients – as in the production of struvite, for example – this could seriously undermine the arguments for applying sludge to farmland.

The *perception of sludge* is undoubtedly a major barrier to accepting it. In the United States the term biosolids was introduced in 1991 by the Water Environment Federation (formerly known as the Federation of Sewage Works Associations). In Denmark the concept of “bio fertilizer” (*biogødning*) was similarly introduced in 2015 by the Industrial Association for Recycling of Resources for Agricultural Purposes (BGORJ).

In a leaflet to farmers, *Hededanmark*, a company providing sludge to farmers, gives the following reasons for accepting it:

- “You reduce your fertilizer expenses significantly
- You add organic matter to your soil
- You add phosphorus, nitrogen and a number of micro nutrients
- You get the sludge and have it spread in the field
- With HedeDanmark as your supplier, you can be sure everything happens according to existing regulations
- You can be sure of a stable supply of fertilizer over the coming years
- Depending on season and geography you may receive an economic subsidy”

[http://www.ressourcegenanvendelse.dk/media/Løsblad - Spildevandsslam.pdf](http://www.ressourcegenanvendelse.dk/media/Løsblad_-_Spildevandsslam.pdf)

Despite these arguments and despite the fact that the Danish EPA (Miljøstyrelsen) approves of using sludge, there still are significant barriers to the use of it. For example, *organic farmers* are not allowed to use sludge<sup>4</sup>. With 6.9 % of all agricultural land<sup>5</sup> (in 2012) organic farms represent only a relatively small potential source of demand. For some years organic farmers have been working on phasing out the use of “conventional” slurry and animal manure. It is clear, however, that alternative sources of fertilizer will be needed to keep up production, and the option of recycling sludge has been discussed intensely. Sociologist Jesper Lassen of Copenhagen University conducted five focus groups interviews, each of them with eight consumers of organic foods, to analyse how this would go down with consumers. He concluded that “organic consumers base their assessment of alternative strategies and technologies primarily on concerns about environmental risks (pollution) and consequences for human health. Broader ideas about ecosystems and the

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<sup>4</sup> Videncentret for Landbrug, Regler for økologisk planteavl.

[https://www.google.dk/?gws\\_rd=cr,ssl&ei=8lGiVvFB6vrKA7eAlJgB#q=%C3%B8kologisk+landbrug+slam](https://www.google.dk/?gws_rd=cr,ssl&ei=8lGiVvFB6vrKA7eAlJgB#q=%C3%B8kologisk+landbrug+slam)

<sup>5</sup> Ministeriet for fødevarer, landbrug og fiskeri (2013), Statistik over økologiske jordbrugsbedrifter 2012, p. 10

recycling of nutrients between the agricultural sector and the urban population are notably absent.” (Lassen, forthcoming).

Similarly, *The Danish Dairy Board* tends to be opposed to the use of sludge. Its industry policy (Mejeriforeningen, 2004) rests on the following guidelines:

- Milk producers do not spread wastewater sludge in the fields.
- Milk producers do not spread degassed slurry in the fields, if the slurry comes from bio gas plants receiving wastewater sludge.
- Milk producers do not use purchased roughage grown in fields to which wastewater sludge has been applied during the past 3 years.

The practical details of the policy implementation need not deter us here. It is important to note, however, that farms with dairy cattle accounted for 19.6 per cent of the total agricultural area in 2014. Thus, in quantitative terms this policy is bound to exert a significant impact on the demand for sludge.

In an interview in *Maskinbladet* in 2006, Carsten Fricke, project manager at Arla Foods’ Environmental Department, explained that “we can’t be talking about hard-core science, as long as the sludge is being screened for only a selection of substances and does not impose any limits on, say, the disputed oestrogenic substances ... Legislation does not take account of the ethical and emotional dilemmas among the consumers, which we have to address ... Legislation is bound to lag behind, at least when it comes to the food sector ... for new substances emerge all the time, the risk of which can be estimated only after some time. This is basically the unknown factor, we are trying to handle.”

In an interview with the author (20 January 2016), Jan Johannesen, Sustainability Director at Arla Foods, confirmed these concerns, adding that markets for some products, such as baby food, may be particularly sensitive to any unwanted residues that might be detected.

Following the food scandals of the 1990s (e.g., the BSE-scandal) *traceability* became a major issue. Thus article 18 of the EU’s General Food Law Regulation 178/2002 lays down that the “traceability of food, feed, food-producing animals, and any other substance intended to be, or expected to be, incorporated into a food or feed shall be established at all stages of production, processing and distribution... To this end, such operators shall have in place systems and procedures which allow for this information to be made available to the competent authorities on demand.”

In the above interview in *Maskinbladet* Carsten Fricke was quoted as saying: “As long as the municipalities do not separate the wastewater from private households from industrial wastewater, we choose to stick to the precautionary principle at Arla, for it is impossible to know for sure what substances will come with the household wastewater.” The problem, of course, is that separating the two sources of wastewater would take huge investments in the sewerage system.

It should be mentioned that Germany has experienced health problems emanating from the agricultural application of wastewater sludge. A brochure from the German *Umweltsbundesamt* explains:

“With the wastewater sludge, pathogens such as bacteria, viruses, parasites and worm eggs are secluded. If the sludge is to be used in agriculture, there is a basic risk of pathogens reaching humans and animals through food and feedstuffs, thereby placing them at risk. These potential hazards are the object of discussion concerning a possible transmission of EHEC to humans as a result of the application of wastewater sludge and other organic materials on agricultural surfaces. The EHEC epidemic in May and June 2011, caused by the EHEC pathogen 0104:H4 made it clear to the public how important such a risk assessment is.”

(Wiechmann et. al. 2016, p. 14, author’s translation)

Moreover, while the Danish EPA (Miljøstyrelsen) approves of the use of sludge, Germany has imposed a series of restrictions on its agricultural application:

“... Thus § 4 of the Wastewater Sludge Order imposes limitations on its application. For example, no wastewater sludge can be applied to surfaces used for the production of vegetables and fruit or on permanent grassland. Furthermore, there are limitations on the application to arable land used for growing forage or sugar beets – provided the sugar beet leaves are used as feed. In particular, food products and feedstuffs for human consumption should thus not be manured with wastewater sludge.”

(Wiechmann et. al. 2016, p. 15, author’s translation)

In connection with the present study five randomly chosen farmers were contacted to hear about their views of sludge. Two of them explained that they were not allowed to use it and had not really considered the issue seriously. Two others had decided not to apply sludge. Finally, one farmer was happily applying the sludge, explaining that he saved a considerable amount of money on this account.

Refsgaard and Magnussen (2006) conducted a survey entitled *Attitudes, experience and knowledge among farmers to recycling of sludge*, and concluded:

In a survey answered by 1050 farmers, attitudes, experiences and knowledge towards use of sludge were investigated. Reasons for use were soil conditioner properties and compensation schemes. Reasons for non-use were fear of toxic compounds and infectious remnants, restrictions on use of land and unfamiliarity with use. There was more knowledge among users than among non-users. Compensation for sludge among farmers implied a perception of sludge as a waste. If farmers must accept sludge, then reliable and complete information from trusted sources is required: economic arguments about agronomic benefits are not sufficient and confidence with other stakeholders and a feeling of justice in solving environmental problems are central aspects.

Refsgaard and Magnussen (2006, p. 49)

A new survey would obviously be required to find out to what extent attitudes have changed. One of the farmers interviewed for the present study explained that he was concerned about future

regulations and the possible implications with respect to the value of his land. “In the worst case it could become unsaleable”, as he put it. Confronted with this statement, Mogens Jensen of Miljøservice Vejen remarked that “we hear that less often nowadays”. Similarly, in an article in *Teknik og Miljø*, HedeDanmark’s Sune Aagoot Sckerl, went as far as claiming that “farmers are now comfortable with the quality and documentation, that the general quality of wastewater sludge has improved year on year and that prices of an integrated farming solution have become highly competitive compared to alternatives.” Although this may be an overstatement, it is conceivable that attitudes have changed towards a higher level of acceptance.

Finally, it should be mentioned that a year ago, Nordjyske Tidende (20 January 2015) reported that “a significant majority in Frederikshavn’s City Council wants to put an end to the application of sludge from wastewater treatment plants to cultivated farmland.... This is a marked departure from the prevailing view of sludge as a resource to be recycled...”

To round off this overview of the demand side, it should be mentioned that farmers do have access to alternatives. For example, Novo Nordisk offers a product called NovoGro, while LeoPharma sells Fertigro. Mash from breweries can also be used to fertilize soil. It has not been possible to find quantitative information on the volumes of such products applied.

## **6. Market interactions – a theoretical synthesis**

As mentioned above, the available data does not allow us to quantify interactions between supply and demand and measure the relative impact of various factors. A quantitative survey of farmers’ attitudes and behaviour with respect to the use of sludge and other inputs would be required to do so. Yet, it is possible to provide a theory-based interpretation of the market behaviour observed in practice.

As regards the supply side, it seems reasonable to assume that it must be relatively price inelastic. Suppliers are forced to dispose of their sludge one way or the other, and agricultural recycling constitutes a major outlet that cannot easily be replaced (cf. Table 1 above). The large price differences found in the DANVA study is consistent with this interpretation.

The demand for sludge is bound to be somewhat more complicated, partly due to the regulations imposed. In the following we shall consider how the demand for sludge will depend on

- Output prices
- The perception of sludge
- The content of nutrients in sludge

The Sludge Announcement (*Slambekendtgørelsen*) lays down that the combined amount of fertilizers from animal manure, sludge and other waste products per hectare is not allowed to exceed 90 kg of phosphorus every three years and 170 kg of total N per year. To illustrate the implications of this, let us consider a simplified mathematical model.

Suppose we have  $N$  nearly identical farms. While on each farm the quality of the soil is perfectly uniform, soil quality varies from farm to farm.

- $C$  is the ceiling on the amount of nutrients that may applied.
- $S$  is the amount of sludge purchased (if any).
- $nS$  is the content of nutrients in  $S$
- $tS$  measures the farmer's expected negative economic value of pollutants in the sludge.

The economic value of applying the sludge on farm  $i$  is

$$\pi_i = \pi_{oi} - S_i p_s - S_i t = \pi_{oi} - (p_s + t) S_i \quad [1]$$

If  $\pi_i$  is positive, the farmer applies  $S_i = C/n$  in order to fertilize up to the ceiling. Otherwise, no sludge is purchased by the farmer since his land is assumed to be of uniform quality.

Suppose farms are numbered so that

$$\pi_{oi} = \alpha - \beta \cdot i \quad [2]$$

$\alpha$  and  $\beta$  being positive constants. Thus, low values of  $i$  have high-quality soil and vice versa.

As  $S_i = C/n$  for those who choose to apply the sludge, it follows from [1] and [2] that profits will be positive only for

$$\alpha - \beta \cdot i > (p_s + t) \frac{C}{n} \Leftrightarrow \frac{\alpha - (p_s + t) \frac{C}{n}}{\beta} > i \quad [3]$$

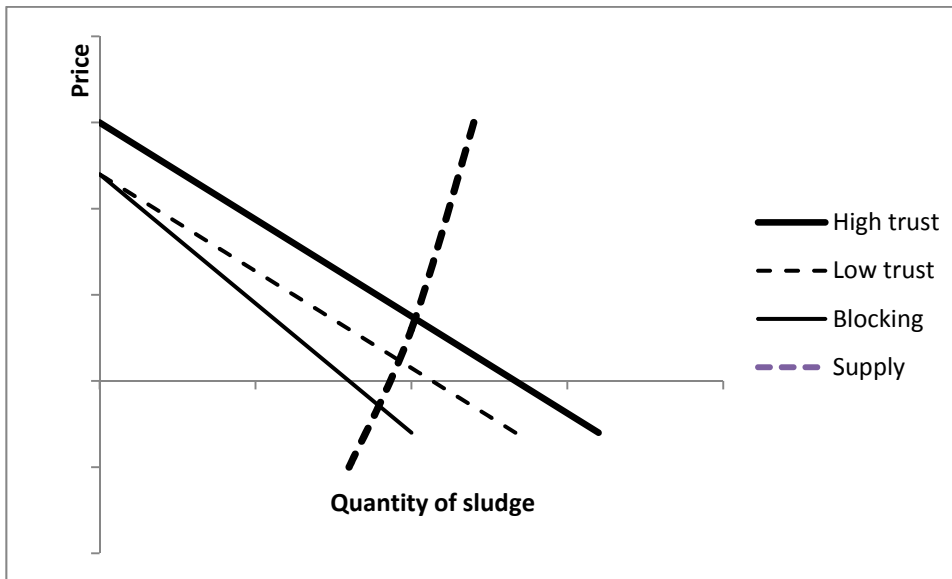
Summing all farms' demand for sludge yields

$$D_s = \frac{C}{n} \left( \frac{\alpha - (p_s + t) \frac{C}{n}}{\beta} \right) \quad [4]$$

Figure 1 shows the supply and demand for sludge as the model describes it. With perfect trust in the product, the solid topmost demand schedule would apply, and prices and quantities would be determined by its point of intersection with the supply curve. A general reduction of trust would displace the demand curve downwards, as indicated by the broken low-trust curve. More realistically, if some farmers trust the product more than others, this will make the demand curve

somewhat steeper. The impact of “blocking” refers to the fact that some farmers (organic farmers or dairy farmers) who might otherwise want to buy sludge, are prevented from doing so by their respective organizations. It should be noted that these institutional barriers prevent a substantial proportion of farmers from buying it. Thus, organic farms and (other) dairy farms account for at least 20 per cent of the total agricultural area, and both of these (partly overlapping) groups are prevented from applying sludge on account of the policies of their respective organizations.

**Figure 1: The market for sludge**



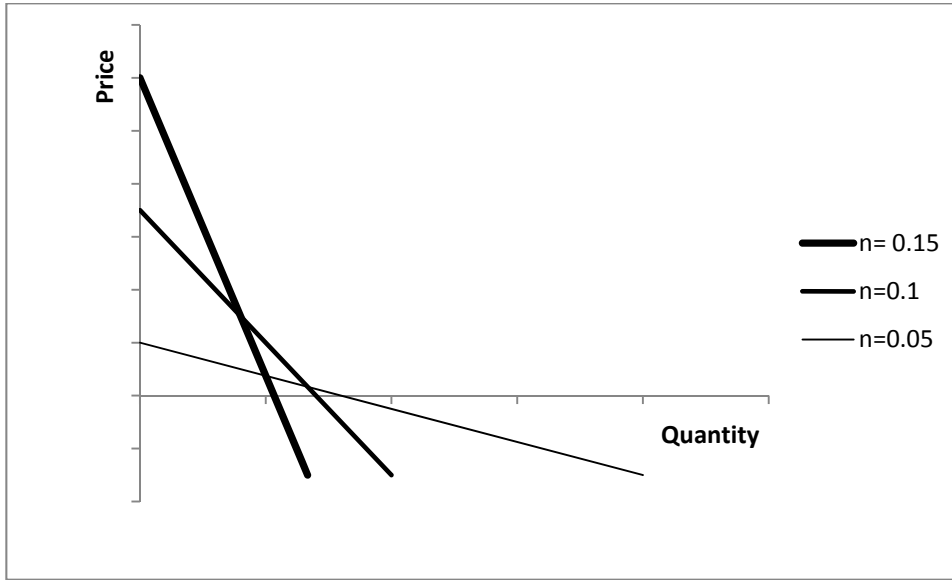
Note also that the prices of farm output do *not* seem to influence the demand for sludge. This is because farmers have been assumed to fertilize “up to the ceiling” – an assumption based on the interviews made. If food prices were to fall sufficiently, this assumption might be invalidated, of course, but in the current situation the quantitative regulations appear to sever the normal ties between input and output prices, at least as concerns sludge.

The demand for sludge obviously depends on its content of nutrients. The question is: how?

Equation [4] shows that two opposing forces are at work. While the first factor of the equation ( $C/n$ ) shows that each of the farmers who buy sludge will have to buy more to reach the limit imposed on the total amount of fertilizer that can be applied, the second factor shows that the number of buyers will be positively related to the content of nutrients.

As illustrated in Figure 2, the combined effect of these two forces seems to be that at low prices the demand for sludge may actually be *inversely* related to its content of nutrients. This may explain why Lassen and Ifversen (2014) found no price effect of reducing the phosphorus content in sludge.

**Figure 2: The impact of nutrient content on demand**



The fact remains, however, that a serious reduction in the content of nutrients is bound to curtail the possibilities of making the sludge market profitable.

## **7. Conclusions and perspectives**

The results of the present study leave little doubt that environmental concerns – and concerns about possible consumer reactions – continue to present a major obstacle to the agricultural demand for sludge. The key issue is how to address these concerns.

The wastewater treatment industry and intermediaries such as HedeDanmark with vested interests in developing the market for sludge may have something to gain from renaming it into bio fertilizer (or biosolids in the US). However, there is usually more to a brand than a name. From the perspective of the farmers and the food industry the stakes are high. Past food scandals have alerted them to the importance of traceability. While some of the past scandals have been due to fraud (e.g. the horse-meat or olive oil scandals), others (e.g. BSE, listeria, salmonella, dioxins, etc.) have been unintended. The EU's General Food Law of 2002 with its demand for traceability came in response to such scandals. Arla's Jan Johannesen explained in an interview for this paper that "it is not what is being tested for, but what is not being tested for that worries us".

From a wider perspective, this question points to a central dilemma relating to recycling in general: *How will it ever be possible to recycle sludge, if this can be blocked by the possibility that it may contain some unknown harmful substance not tested for?* If recycling has to wait until all untreated waste is perfectly safe, it will never happen. On the other hand, recycling based on imperfect treatment systems is likely – or perhaps even bound – to give rise to occasional "scandals".

One possibility, of course, is to separate wastewater sources as well as treatment facilities to a much higher degree than is currently being done. Even the traceability of industrial wastewater contents disappears as soon as it enters into the public sewerage system. In fact, it disappears before then whenever the industrial wastewater contains run-off from roofs and pavements, lawns, etc. The challenge is that establishing parallel wastewater treatment systems with perfect traceability will be highly expensive, perhaps even prohibitively so.

A second possibility is to continue improving the treatment of sludge. It is technically possible to impose even stricter regulatory standards on sludge for specific purposes, to label it, and market it. However, this does not rule out the possibility that it may still contain some unknown harmful substance not tested for. The suspicion lurks, therefore, that even this approach has its limitations – limitations which are basically rooted in a (mis-)conception that there exists an absolutely no-risk alternative to the use of sludge.

A third alternative is to extract the nutrients from sludge. The extraction of struvite by Stjernholm (Miljøstyrelsen 2014) is a pertinent – and highly promising – case in point. This approach is bound to reduce the agricultural value of the remaining sludge, as shown in the previous Section, requiring some it to be disposed of in alternative ways.

Perhaps a kind of Consensus Conference involving lay citizens as well as industry representatives, NGOs, authority representatives and researchers would be helpful in addressing the above dilemmas and mapping the road forward.



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