FINAL REPORT OF RISK ASSESSMENT OF BIOGAS PRODUCTION IN THE BALTIC SEA REGION FROM A NUTRIENT MANAGEMENT PERSPECTIVE.

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1.0 Brief history and list of Biogas Installations

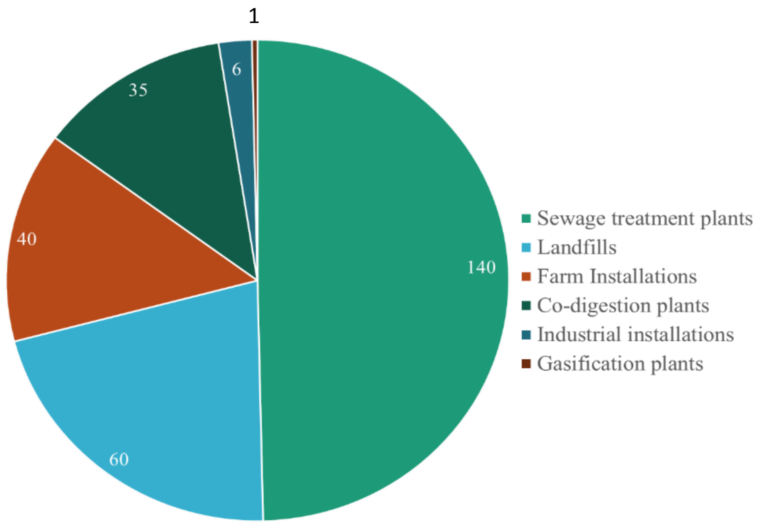
Biogas production is one of several alternatives to meet the goals of sustainable energy solutions and waste management. Biogas is produced by microbial degradation of organic material (biomass) under oxygen free (anaerobic) conditions. This is also called anaerobic digestion (AD) (Harrysson and Von Bahr, 2014; Wellinger et al., 2013). Even though the potential of biogas production is still growing all over the world, it gained its popularity in 1970s, amidst rises of energy prices and worries about the detrimental impact of fossil fuels on global warming (Nkoa R, 2014). In addition, it would be worth noting that China and India are the two countries to which the history of biogas production rooted since the mid-19th century (Biogasportalen, 2015).

Swedish history of biogas production only began in the mid-20th century, when wastewater treatment plants (WWTP) were trying to reduce sludge volumes but also to reduce odour and eliminate infectious matter. The city of Stockholm has two sewage treatment plants dating back to 1934 and 1941 respectively; where biogas production began already in 1940s (Biogasportalen, 2015, Olsson L. & Fallde M., 2013).

Today, there is a total of 282 biogas plants in Sweden and they comprise of various types, namely: Sewage treatment plants, 140 in number, producing 36% of the total biogas (1974 GWh); Co-digestion plants 35 (44% of the biogas); Farm-based installations 40 (3% of the biogas); Industrial plants 6 (6% of the biogas); one Gasification plant (2% of the biogas); and 60 Landfill installations (9% of the biogas). However, landfills and gasification plants will not be further discussed in this report because they are classified under an older, different legislation.

A recent report of Swedish efforts in development of waste treatment, indicates that there has been a reduction of 6 landfills within a year, from 60 in 2015 to 54 in 2016. (Avfall Sverige., 2016)

Fig.1; Plot of various types and number of biogas plants in Sweden.



http://www.biogasportalen.se/BiogasISverigeOchVarlden/BiogasISiffror/Anlaggningar.2017/04/07.

Table 1: County-wise distribution of Biogas plants, reactor volumes and the amount of biogas produced in 2015. Landfills and gasification plant not included.

County	Number of plants	Reactor volume (M^3)	Biogas produced (GWh)
Blekinge	3	2, 850	10,1
Dalarna	9	10, 271	22,1
Götland	1	8, 700	22,9
Gävleborg	5	5, 410	15,5
Halland	14	40, 900	71,0
Jämtland	10	6, 805	10,5
Jönköping	10	23, 170	51,8
Kalmer	11	21, 125	41,4
Kronoberg	5	16, 483	32,3
Norrbrotten	6	12, 380	7,6
Skåne	37	139, 815	379,9
Stockholm	10	90, 163	203,3
Södermanland	6	14, 824	44,7
Uppsala	7	17, 160	53,5
Värmland	7	4, 640	9,4
Västerbotten	6	21, 540	52,5
Västernorrland	10	40, 750	93,1
Västmanland	8	23, 510	61,7
Västra Götaland	38	106, 570	332,1
Örebro	12	34, 060	95,3

Östergötland	12	34, 957	149,7
Total	**227**	**676, 083**	**1721,1**

http://prescriptionmotorcycleeyewear.com/lan-karta-over-sverige.html accessed (30-06-2016)

Fig 2. Map of Sweden showing all the counties to support the table of biogas plants grouped by counties.

Biogas production in Sweden has increased over the years due to a high degree of environmental consciousness in the legislature and for economic reasons. The Swedish Gas association's long-term vision of "Green gas 2050" describes how Sweden can reach a carbon neutral industry with gas (fossil-free road transport, heat and electricity sector, as well as cleaner maritime sector with gas) and it predicts a further increase in the number of biogas installations in the future. (http://www.energigas.se,15/05/2017).

1.1 Feedstocks/Substrates

Substrates are the organic feedstocks for anaerobic digestion (AD) (Quanguo Zhang et al, 2016). As researchers continue to discover new organic material for AD, one can say that there are probably many more types of organic material that can potentially be used for biogas production, than those used today.

The main source of organic material for biogas production in Sweden today is sludge from municipal wastewater treatment plants; reason why the number of biogas plants of wastewater treatment type is the highest.

Sewage sludge refers to the residual of a dilute suspension of solids which contains more than 90% moisture, captured by a wastewater treatment process (Christensson K. et al., 2009, Solon K., 2015). Due to strict environmental regulations, sludge from WWTPs cannot be disposed of or reused in any arbitrary manner. Cost is an important factor to consider in sludge disposal. Typical methods of sludge management are: reuse (anaerobic digestion for gas production), disposal in landfills and incineration (Solon K., 2015). To dispose of the sludge, it is worthwhile to remove water from the sludge. The removed water with special characteristics, called reject water, is prohibited to be discharged into surface waters as WWTP effluents. It is assumed, that for just 2 % of the total influent flow in a WWTP; 10-30 % of nitrogen load and 10-80 % of phosphorous load, is found in reject water (Dosta et al., 2007 as stated in Solon K., 2015).

Other common substrates for biogas production in co-digestion plants include: slaughterhouse waste, waste from the food and feed industries, source-sorted food waste and manure. Examples of other materials which are also treated in these facilities include waste from grease traps, fryer fat, wastes from the dairy and pharmaceutical industries, grass silage, and distillation waste (residues from ethanol production). Different crops and waste from the agricultural sector are also quite important substrates for biogas production.

Other, less common materials that are currently being evaluated for biogas production include algae, grass, feathers and woody biomass (e.g. willow) (Anna Schnürer and Åsa Jarvis, 2009). Of all animal manures in Sweden, a fraction, containing 28 and 38 % of total (N) and phosphorus (P), has the economic and technical potential to be digested. In addition, the introduction of source-separating systems is a major step in achieving high-quality digestate from organic residues containing a small proportion of N and P; from an agricultural perspective (Salomon. E & Wivstad. M., 2014).

Below is a table characterizing different substrates of agricultural farm biogas installations, to indicate the amounts of different variants of nitrogen, phosphorous and other elements which could be found in digestate.

Table 2. Characterization of some different substrates before digestion and digestate. Mean values of analyzes from several samples, where the variation can be large between sampling cases in the same farm. Adapted from Rening av avloppsvatten i Sverige 2014.

Example from four diff studies	Input substrate and digestate	content of dry matter %	pH	Kilogram per ton							
				Carb-on	Total-N	Ammo-nium N	Phosp-horous	Potas-ium	Sulphur	Mag-nesium	Cal-cium
1) Pilot study mass fractions in percent of input substrate	Cow liq manure	8,9	-	41	3,1	1,3	0,6	3,5	0,3	-	-
	Chicken solid manure	65,8	-	280	29,7	4,0	9,7	19,1	4,2	-	-
	Digestate cow liq manure 86 % & Chicken solid manure 14 %	9,1	8,0	37	6,4	4,3	1,7	5,4	0,6	0,9	2,3
	Digestate Cow liq manure 80,5 % & chicken Solid manure 19,5 %	12,6	8,0	52	8,9	5,4	2,6	7,4	1,1	1,5	3,4
2)Operational farm Biogas plant A	Cow liq manure	7,3	-	33	4,2	2,4	0,7	2,9	0,5	0,6	1,1
	Cow deep straw manure	22,1	-	81	5,4	0,9	1,0	5,8	0,9	1,0	1,9
	Digestate not separated	6,2	-	26	4,2	2,6	0,7	3,5	0,4	0,6	1,1
	solid digestate separated	26,5	-	114	6,5	1,6	2,9	3,6	1,3	2,5	4,5
	liquid Digestate separated	2,8	-	11	3,4	2,4	0,3	3,4	0,2	0,3	0,6
2)Operational farm Biogas plant B	Pig liquid manure	5,6	7,1	25	4,7	3,2	0,7	2,0	0,5	0,5	1,1
	Digestate	2,8	7,8	10	4,1	3,4	0,5	2,1	0,3	0,3	0,8
2) Operational farm Biogas plant C	Pig liquid manure	7,9	-	34	4,8	2,6	1,5	2,9	0,5	0,5	2,5
	pig deep straw manure	35,0	-	154	7,0	0,7	2,2	13,0	1,1	1,2	4,2
	maize&silage	28,0	-	136	5,3	0,4	0,7	3,2	0,3	0,3	0,8
	Other substrates	6,8	-	29	4,0	2,1	1,1	2,9	0,3	0,4	1,7
	Food waste squized	14,0	-	76	3,8	0,4	0,4	1,3	0,3	0,2	1,2
	Digestate	3,4	-	15	3,2	2,3	0,9	2,6	0,2	0,3	1,4

The table above shows an overview of how much total nitrogen and total phosphorous can be found in substrates. However, these values would vary with the digestion technology utilized, especially in a co-digestion plant.

Table 3: Feedstocks or substrates of biogas production by anaerobic treatment in 2015; tons by wet weight.

Type of plant	Organic house whole waste	Waste water sludge	manure	Industrial food waste	Slaughterhouse waste	Energy crop	Others
Wastewater treatment	63 385	6160 292	0	38 914	0	0	185 309
Co-digestion	299 909	0	586 526	274 830	141 884	80 441	203 803
Farm installations	0	0	307 233	4 565	4 235	0	4 310
Industrial	0	0	0	114 792	0	0	0
Total	363 294	6 160 292	893 759	433 101	146 119	80 441	393 244

Adapted from: produktion och användning av biogas och rötrester år 2015. (Production and use of biogas and digestate in 2015)

1.2 Biogas production process. Case example: Linköping Biogas AB Plant

In 2009, the total digester volume in Sweden was estimated to be a little less than 500,000m^3 and the reactors' sizes ranging between 100 m^3 to about 30,000 m^3. Generally, biogas production can be a one step (single digester) or two steps (hydrolysis and acidogenesis separated from acetogenesis and methanogenesis) process. Linköping biogas AB has a permit to process up to 125,000 tons of substrate each year. It consists mainly of food waste (43 %), waste from industrial food processing spillage (28 %), slaughter house waste (23 %) and of other vegetable substrate (6 %). The production of biogas occurs in a total of four Continuously Stirred Tank Reactors. Three digesters with volume of 3700 m^3, are working in parallel and the fourth one (post digester) with a volume of 6000 $m^{3,}$ specifically adapted for methane production, completes the digestion process (Biogasportalen, 2015, Eriksson L. & Runevad D. 2014).

The complex process of AD, converting organic material into biogas by micro-organic enzymatic activity, can be divided into four stages; hydrolysis, acidogenesis, acetogenesis and methanogenesis. During hydrolysis, insoluble substrates are degraded into monomers and oligomers by use of water. Acidogenesis further breaks down the monomers and oligomers into volatile fatty acids (VFA), carbon dioxide (CO_2), hydrogen gas (H_2) and acetate. It is the quickest step of AD conversions and therefore small changes do not affect the overall speed of AD (Gerardi, 2003). Acetogenesis is carried out by acetate-forming bacteria which grow in symbiotic relationship with methanogens. Acetate forming bacteria digest VFA by fermentation into acetate, hydrogen and carbon dioxide. Lastly, methanogenesis takes place when methanogens convert acetate, carbon dioxide and hydrogen into methane (Gerardi, 2003). The optimum temperature (in which the micro-organism grows fastest and works most efficiently), varies among species. And depending on this temperature, they can be divided into different groups: psychrophilic, mesophilic, thermophilic, and extremophilic/hyperthermophilic (Noha and Wiegel 2008, in Anna Schnürer & Åsa Jarvis, 2009). Typically, the optimum temperature for a specific organism is strongly linked to the environment from which it originates. For example, low optimum temperature (around 10º C) micro-organisms (psychrophilic temperature range), can be found in marshland or in a septic tank, whereas human intestinal bacteria, such as Escherichia coli, grow best at 37° C (mesophilic temperature range). Organisms with an optimum temperature above 50° C are called thermophiles, and those that grow above 65° C are called extreme thermophiles (Noha and Wiegel 2008, in Schnürer A. & Åsa J., 2009). Like Linköping Biogas AB, most biogas plants in Sweden are operating at a mesophilic temperature, though, there are a few thermophilic plants. The raw biogas produced contains 45-85 % methane, 15-45 % carbon dioxide and, depending on the conditions of production, it may also contain hydrogen sulphide, ammonia and nitrogen. While the substrate is usually pumped into the digester, the biogas is collected from the top of the container, and the residue (digestate) is removed by pumping or through an overflow for later storage or recirculation into the process (Biogasportalen.se- Swedish Gas Association, March 2011).

Biogas digestate is a nutrient-rich substance that can easily be used as fertilizer. It consists of leftover indigestible material and dead micro-organisms cells, with a volume ranging around 90-95 % of what was initially fed into the digester (Kathijotes. N., et al, 2015). The C/N ratio in the digestate decreases, compared to that in the feedstock after anaerobic digestion process, because a large fraction of carbonaceous compounds is converted to methane and carbon dioxide; and collected as biogas. This decrease in the C/N ratio results in an increase in the nitrogen content. In Sweden, pumpable substrate or substrate solution at TS 10-12 % has an outgoing digestate of 2-6 % solid fibre fraction and 94-98 % liquid fraction (Avfall Sverige, 2014; Persson et al, 2012). In 2015, about 2,7 million tonnes of digestate was produced in Sweden. 1,7 million tonnes of digestate were produced from the then existing 35 biogas co-digestion plants. Of the total of bio-manure produced, 81% was used as fertilizer in the arable land (Avfall Sverige, 2016).

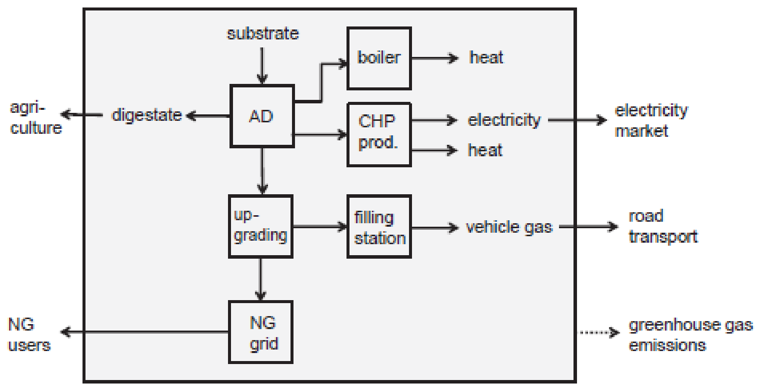


Fig. 3. Schematic representation of the Swedish biogas system. Arrows represents possible but not always required pathways. GHG emissions may be a consequence of the actions taking place within the system, hence this arrow is dotted. Adapted from Olsson. L & Fallde. M, 2014.

1.3 Biogas as vehicle fuel

In Sweden, 63% of the biogas produced is upgraded to vehicle fuel as LNG/CNG, or injected into the gas grid. There are 59 upgrading plants with different technologies (water scrubber, chemical scrubber, membrane filtration, pressure swing adsorption (PSA), organic physical scrubber and cryogenic upgrading) purifying biogas for 217 filling stations, suppling gas to 44,000 cars, 2,200 buses and 750 trucks. Part of the upgraded biogas is injected into the existing natural gas network for district heating. A total of 465 GWh was injected into the gas grid in 2015 (Persson T., IEA Bioenergy task 37).

1.4 Biogas produced

Table 4: Total amount of biogas production in Sweden from 2005 to 2015 (GWh), excluding the amount from landfills and gasification plant.

Type of Plant	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Wastewater treatment	559	582	573	605	615	614	638	660	672	679	697
Co-digestion	163	184	205	240	299	344	416	507	580	717	854
Farm Installations	12	14	13	15	18	16	20	47	77	44	50
Industrial plants	94	91	125	130	106	114	129	121	117	123	121
Sum	**828**	**871**	**916**	**990**	**1038**	**1088**	**1203**	**1335**	**1446**	**1563**	**1722**

Adapted from: produktion och användning av biogas och rötrester år 2015. (Production and use of biogas and digestate in 2015)

Table 5. Amount of digested sewage sludge and solid digestate produced by respective types of biogas installation, amount and % used as biofertilizer and the number of biogas plants certified by either REVAQ or SPCR 120 in 2015.

Type of Biogas plant	Production of digestate (tons wet weight)	Use of digestate as biofertilizer (tons wet weight)	Use of digestate as biofertilizer (%)	N0 of certified installations (REVAQ and SPCR 120)
Wastewater treatment	650 694	182 057	28	35
Co-digestion	1 710 412	1 689 834	99	19
Farm Installations	314 895	314 895	100	
Industrial Plants	10 576	0	0	0
Total	2 686 577	2 186 786	81	54

Adapted from: produktion och användning av biogas och rötrester år 2015. (Production and use of biogas and digestate in 2015)

Depending on the feedstock(s) material, anaerobic digestate applied in agricultural fields has shown to have positive results on soil, in terms of fertilizer value and as soil organic amendment when properly handled and managed. As soil amendment it would as an addition to the soil improve or maintain the soil's physical, chemical or biological properties (AFNOR: FD CR 13456, 2001 as stated in Nkoa R., 2013). Biochemical analyses of digestate reveal that some solid digestates show a greater mineral nitrogen fraction (51-68 % total N) relative to the organic fraction (Paavola. T et al., 2008) and suggesting that they are best used as fertilizers. On the other hand, digestate that have a low mineral nitrogen fraction (24-36% total N) relative to the organic fraction, has a higher potential of valorization as organic amendment (Teglia et al, 2011b).

However, it is documented that the application of digestate from biogas production to arable land as fertilizer or organic soil amendment, in addition to the risks of atmospheric pollution as ammonia and nitrous oxide emission, leads to significant nutrient leakage in to the soil and water bodies (Colazo. Ana-B. et al, 2015 & Nkoa R., 2013). Nutrient Pollution (eutrophication) is a major environmental concern when excess nitrogen and phosphorous leak and contaminate surface and ground water courses as well as major water bodies.

Table 6. Average values of nutrient and heavy metal content in bio-fertilizer from Linköping biogas plant (Tekniska verken, 2015). Components between and within plants vary depending on substrate composition. Adapted from Eriksson Linnea and Runevad David, 2016.

Parameter	**Quantity**	**Unit**
Total Nitrogen (N-tot)	3,6–5,7	kg/m^3
Available Nitrogen (NH4-N)	2,3–3,3	kg/m^3
Total Phosphorus (P-tot)	0,3–0,9	kg/m^3
Total Potassium (K)	1,1–1,5	kg/m^3
Sulphur (S)	0,3–0,6	kg/m^3
Calcium (Ca)	1,1–1,7	kg/m^3
Magnesium (Mg)	0,07–0,1	kg/m^3
PH	8,0–8,5	
Total Solids (TS)	3,0–4,3	%
Lead (Pb)	1,1–12	mg/kg TS
Cadmium (Cd)	0,3–0,5	mg/kg TS
Copper (Cu)	47–76	mg/kg TS
Chrome (Cr)	5,5–12	mg/kg TS
Mercury (Hg)	0,05–0,06	mg/kg TS
Nickel (Ni)	10–35	mg/kg TS
Zink (Zn)	144–184	mg/kg TS
Silver (Ag)	1,0–1,0	mg/kg TS

In a wastewater treatment plant, the residue of sewage sludge treatment is called digested sewage sludge and contains a high-water content. De-watering is therefore required before spreading the digestate sewage sludge in arable land. The liquid from this de-watering process is called reject water (Swedish gas association 2011). In Sweden, digested sewage sludge which has been certified can be used as fertilizer, while the liquid fraction (reject water) is returned into the system.

2.0 Review of treatment methods used for solid and liquid digestate from biogas processes

The cost of handling digestate due to its high-water content is relatively high compared to the revenues from digestate value. A solution to this could be to process the digestate (i.e. reduce the mass and volume), leading to high concentration of nutrients and to ease the handling of the digestate. It could also have a positive impact on all subsequent activities in the whole digestate management chain (Berglund, 2010; Persson et al, 2012, as stated in Eriksson. L & Runevad D., 2016).

Although, the technology of processing the digestate is costly compared to the revenues, it can be especially motivating in livestock intensive areas where there is a high accumulation of nutrients. High levels of nutrients may restrict the application, or otherwise overload the land and which, if it occurs, eventually leads to leaching and eutrophication (Dahlin et al., 2015). The nutrient distribution problem (long and expensive transport), due to legislative pressure on nutrient management and environmental protection, can be solved by either reducing the total volume of the digestate to be handled or by reducing the limiting factors for land application (Wellinger et al., 2103).

Digestate can be partially or completely treated. Partial treatment usually targets volume reduction while the complete treatment upgrades the digestate to pure water, fibers/solids and concentrates of mineral nutrients. Digestate processing begins with the separating the solid phase from the liquid. The solid fraction can subsequently be directly applied as fertilizer in agriculture or it can be composted. Additionally, there are several different techniques that can be used for each digestate treatment option. Depending on the desired end product, partial, complete or variations of treatments can be applied.

2.1 No treatment option

In Sweden, as in many EU countries, the no-treatment option is the most common in-use for digestate from co-digestion plants and farm installations (Saveyn & Eder 2014., Olausson. J). This option is attractive because of low or no processing cost, as well as its simplicity (uncomplicated process with little or no wrong). This is achievable through contacts for sufficient land disposal on surrounding areas. As stated above, where land application is limited, transportation distances and cost become very high. The application of composted digestate is to some extent said to be problematic due to the odour emissions. However, the process can further be improved to decrease the odour emissions by increasing the process time and increasing aeration or operating the composting process in a closed chamber (Sheets et al., 2015, as stated by Eriksson. L & Runevad D., 2016). Also, the investment cost of composting digestate is considered high. Though the cost might be difficult to determine in detail, given that the techniques vary considerably, it is estimated to be at a minimum of 10 MSEK (Svenska Renhållningsverksföreningen., 2005 as stated by Eriksson. L & Runevad D., 2016).

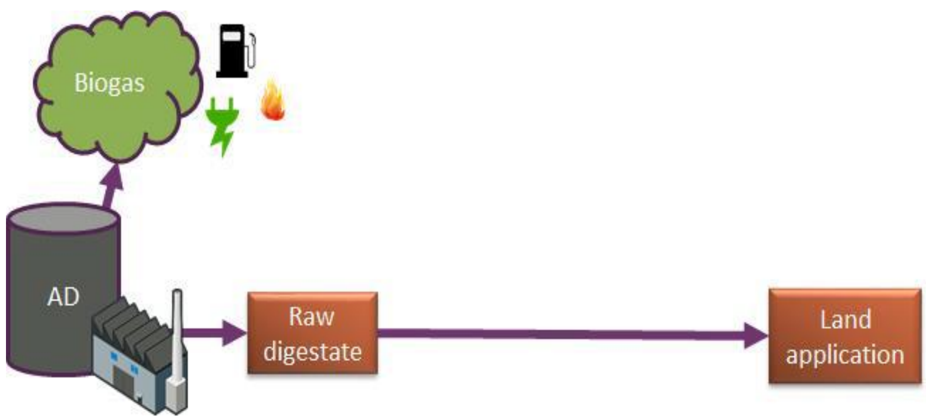


Fig 4. No treatment. Digestate is being directly land applied without further treatment. An attractive option when sufficient farmland is available nearby. Adapted from (Eriksson L. & Runevad D., 2016).

2.2 Partial processing of digestate

Screw Press is a common mechanical solid-liquid separation technique, used for partial processing of digestate (Drosg et al.,2015, as stated in Eriksson. L & Runevad D., 2016).

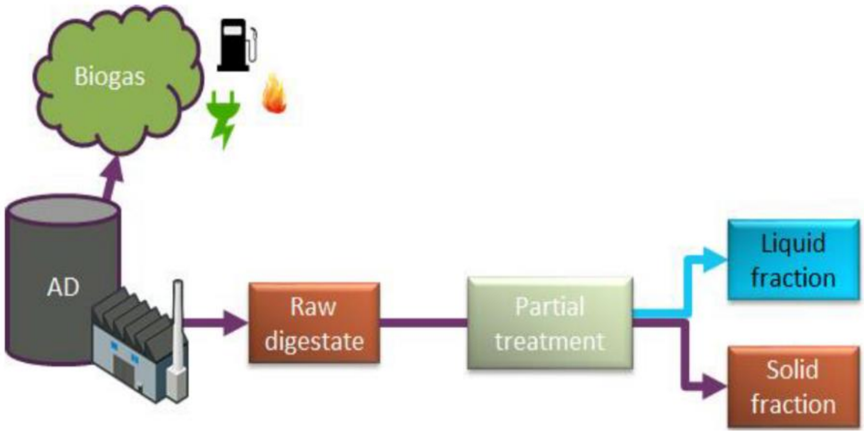


Fig. 5 Partial treatment: Digestate is treated with simple techniques resulting in two fractions. Adapted from (Eriksson L. & Runevad D., 2016).

The method uses pressurized filtration where digestate is pumped into the center of the press and forced against a surrounding cylindrical sieve. A screw rotates within this sieve, slowly transporting the digestate along the cylinder while the liquid can filtrate through and be collected by the surrounding container. By thickening the central shaft of the screw, pressure against the sieve is increased and water is discharged. The solid fiber fraction exits at the plate opening. The degree of dewatering is adjusted mechanically by increasing or decreasing the flaps opening at the discharge end of the screw. Screw press dewatering requires relatively low energy consumption of about 0.4-0.5 KWh/m^3 digestate and a solid fraction from the dewatering process is typically around 20-30 % TS (Drosg et al., 2015).

Digestate separation into solid and liquid is greatly influenced by the mesh size, flocculants, and characteristics of the digestate, such as fibre and TS content (Drosg et al., 2010). The distribution of nutrients and other elements is affected by separation efficiency which varies with the techniques. The efficiency of separation could be determined based on how clean the filtrate is or how dewatered is the solid fraction.

Table 7. Separation efficiency for each fraction. Outcome can vary greatly depending on several factors, e.g. Separation technique, digestate, flowrate etc.

SEPARATION EFFICIENCY	**Solid high TS**	**Solid low TS**
Liquid Low TS	*Good separation*	*Clear liquid fraction Bad dewatering of solid fraction*
Liquid High TS	*Unclean liquid fraction Good dewatering of solid fraction*	*Bad separation*

During mechanical separation, nutrients and other constituents, both organic and inorganic, will distribute between each fraction individually. Fig.6 illustrates the separation characteristics of the technique hitherto mentioned. The separation efficiency varies with the technique applied and digestate characteristics, but also on the effectiveness of anaerobic digestion. The degree of digestion determines the amount of organically bound nutrients against mineralized nutrients. And, a concentration of an organically bound substance (i.e. in solids) is more likely to shift towards the solid fraction, while the concentration of a mineralized substance (i.e. soluble in liquid) shift towards the liquid fraction (Drosg et al., 2010). However, the separation characteristics can be manipulated by for example adding chemicals. For example, the addition of flocculation additives (e.g. polymers) can increase separation of up to 95 % (Meixner et al., 2015, as stated by Eriksson L. & Runevad D., 2016). Polymers are a commonly used processing aid used in the waste water treatment sector, due to its flocculation properties. Therefore, there is an interest of using polymers in the biogas sector when dewatering digestate (Eriksson L. & Runevad D., 2016).

The WWTP where I visited uses polymers and the screw press method - the literature I referred to for studies conducted in Sweden stated the same. Across the spectrum of the plants in Sweden; in my opinion, I say about 80 % uses polymers. The polymers are obviously digested in the digester but however form part of the digestate applied in arable land (personal communication with I'Ons David-development engineer Gryaab AB, Göteborg).

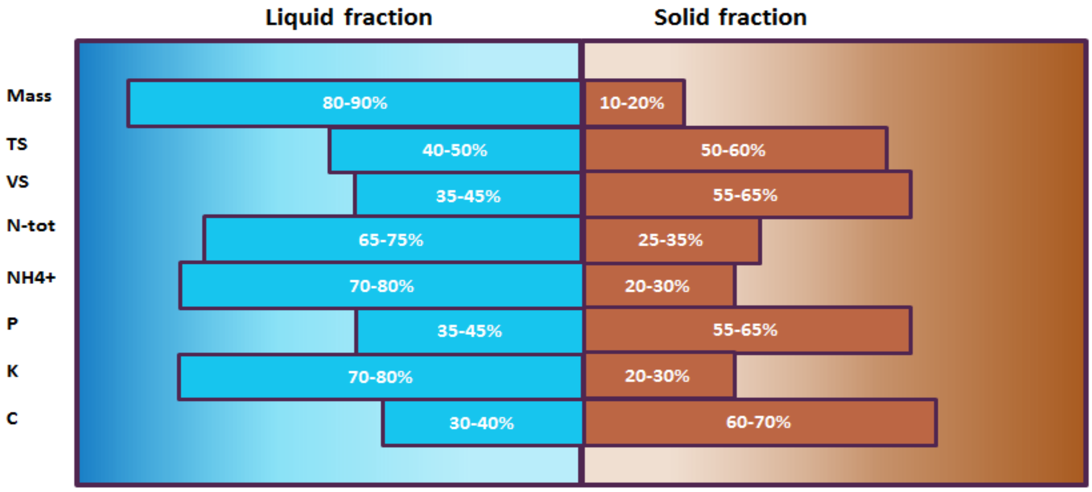


Fig 6. Distribution of the principal constituents after solid–liquid separation; adapted after Bauer et al. (2009) as stated by Drosg et al., 2015).

2.3 Reject water treatment methods

Based on the history of the techniques employed in treating reject water in most of the wastewater treatment plants in Sweden, it can be concluded that in 2017, nitrification denitrification in Sequence Batch Reactor (SBR) is still the dominant method for separate reject water treatment (Stenström F. et al; 2017). Nitrification denitrification in an SBR is a variant of activated sludge technology. It refers to the bio flocks which naturally occur when the residence time of the sludge is longer than the hydraulic residence time (i.e., SRT> HRT) and a noticeable sludge concentration is obtained in the system.

The first permanent full-scale wastewater treatment in Sweden was a SBR for nitrification denitrification, which was commissioned in 1991 at Nykvarn's wastewater treatment plant in Linköping.

The reason why SBR became common for reject water treatment, is that it is cheaper to build than a separate bioreactor and separate sedimentation basin, and partly because the even flow of reject water fits well for an SBR with minimal risk of hydraulic overload. Another reason is its process flexibility, where it is easy to vary pre- or post-denitrification, different times for anoxic and aerobic phases, as well as sedimentation time. SBR systems are designed with a leveling tank prior to the reactor to enable batch-wise pumping (Stenström F. et al; 2017).

The Nykvarn's sewage treatment plant located in Linköping uses the SHARON technique; and it is the only plant in Sweden which came into operation in 2009. SHARON is an acronym for Single Reactor System for High Activity Ammonia Removal Over Nitrite. As the acronym suggests, ammonium is not oxidized all the way to nitrate but only to nitrite. The process is cheaper and more environmentally friendly than conventional nitrification denitrification because theoretically 25 % less air volume and 40 % less carbon source is required. According to Hellinga et al., 1998, as cited by Stenström et al., 2017, the primary idea behind this process is to achieve high conversion rates and to be a volume-effective process. Obtaining very low nitrogen levels in the effluent water is therefore subordinate purpose.

Sjölunda in Malmö and, Sundets in Växjö uses the ANITA ™ Mox process in treating digestion returns by Moving Bed Biofilm Reactor (MBBR). The process is especially recommended for plants with digestion systems combined with thermal hydrolysis, a combination that is used to increase biogas production and reduce the amount of sludge produced. The increased nitrogen load after thermal hydrolysis is preferentially treated in the ANITA™ Mox process under sustainable conditions (Stenström et al., 2017, www.veoliawatertechnologies.com).

The Slottshagen's sewage treatment plant in Norrköping treats wastewater with nitrification-denitrification in SBR. The purpose of the SBR is to increase the overall reduction of nitrogen in the winter as well as reduce load to the main treatment step (Stenström et al., 2017).

In some plants, for example Gryaab AB in Göteborg, the reject water is returned into the system at a point where it will not affect the process but is easily recovered downstream. The extra nitrogen loading of about 20 % does not cause capacity nor operational problems as the plant is designed to cope with this factor (personal communication with I'Ons David-development engineer Gryaab AB, Göteborg). When the legislative limits of nutrients have been reached, the effluent can be released into the receiving waters. Effluent release is also permissible for plants without set nutrient limits but their locations or regions form the basis upon which this is agreed. The regions in the east coast of Sweden (from Norrtälje upwards in the north) have no regulation nor limit on the amount of discharge into the watercourses. This area has a very small population and large water bodies, and has a history of low effluent concentration. (Mattsson Ann; Gryaab AB, Göteborg).

Table 8. Reject water treatment techniques/ management process in some facilities.

Wastewater treatment Plant	**Reject water treatment technique or treatment related information**
Sörmland Vatten och Avfall AB. 10 treatment plants in the county.	*All reject water passes through the inlet of the plant and back to the process. A buffer volume of reject water is added for dilution. Applies to all the ten facilities* (Öberg E. research engineer)
Klippans Kommun	*Reject water is pumped into a leveling pool to get a dilution of the ammonium and re-pumping into the plant. In this way, the ammonium peaks are reduced during the operation* (Andersson B. Klippans Kommun, VA-department)
Stockholm Vatten VA AB	*ANITA MOX – It has been operational since February 2017* (Gottås H.)
Kalmer Vatten AB	*The reject water goes back into the process* (Arnesdotter B. Environmental engineer)
Skebäcksverket in Örebro	*No specific treatment for reject water. Reject water is added to the biological treatment. The process is an ARP (Active Return Sludge Process), which means that the return sludge is pre-treated in an ARP-tank before entering the biological tank. Both the ARP and the biological tank are intermittently aerated for nitrification and denitrification. The ARP has extra capacity when it comes to nitrification (and denitrification), since the microorganisms are "hungry" for substance and waste water has not yet been added.* (Sundvall T. process engineer)

2.4 Efficiencies of some reject water treatment techniques compared

As selected examples, the table below is a comparison of three different reject water treatment techniques of some plants in Sweden. The comparison is intended to show the efficiencies of the treatment techniques at favorable conditions of temperature, PH and concentration of different substances.

Table 9. Comparison of reject water treatment techniques

Operational Characteristics	**SHARON at Nykvarn in Linköping**	**ANITA™ Mox in Växjö**	**SBR at Slottshagens in Norrköping**
Reactor Volume	1 240 m3	297 m3	1 050 m3
Reject water flow	250 m^3/d	150 m3/d	215 m3/d
Hydraulic Rention Time (HRT)	5,0 d	2,0 d	4,7 d
Incoming conc of Total Nitrogen	1 800 mg/L	950 mg/L	1 370 mg/L
Outgoing conc of Total Nitrogen	350 mg/L	200 mg/L	270 mg/L

Reduction grade of Total Nitrogen	81%	79 %	81 %
Reduction grade NH4-N	94%	92 %	99 %
Fraction of rejectwater flow of the incoming mainstream flow	0,6%	0,7 %	0,5 %
Volumetric reduction of TN by actual load	0,29 kg TN_{red} /m^3, d	0,38 kg TN_{red}/m^3, d	0,23 kg TNred/m3, d
Energy consumption (aeration + stirrers)	1,8kWh/kg TN_{red}	1,4 kWh/kg TN_{red}	3,5 kWh/kg TNred
Working time (operational surveillance, maintenance, analysis)	11,5h/v	6 h/v	5,5 h/v
Operational cost (energy + worktime + ethanol)	9kr/kg TN_{red}	5 kr/kg TN_{red}	19 kr/kg TNred
Operational cost distribution energy/worktime/ ethanol	11/25/64%	24/76 %	16/8/76 %

2.5 Uses of digested sewage sludge from WWTP

Fertilization of arable land has been the single largest use area of digested sewage sludge in the 1980s and 1990s. Agricultural use, including the cultivation of energy crops, has varied between 10 and 50 %, but has in recent years been around 25-28 %. Most of the Swedish sludge (close to 90 %) meets the quality standards for metals (limit values) and organic substances (target values) but the public, for aesthetic reasons, is still concerned on its use in agriculture. Sewage plants recycle only a small fraction of the sludge. It is historically regarded with suspicion, basically, it is about trust. There is an unwillingness to use sewage sludge as it has a long history of high metal content. Anaerobic digestion uses well defined substrates that are easy to trace back, whereas sludge in the end of wastewater treatment includes chemicals and e.g. pharmaceuticals. Even though the sewage sludge meets standards and limits for pollutants, and, has come a long way regarding quality, it still has a bad reputation.

Digested sewage sludge also attracts increased interest among forest research scientists and forest companies, and therefore the possibility to be used in forest fertilization. Sludge could be used to fertilize forests and to compensate the forest land for the nutrients and metals (Ca, Mg, K) that leak out due to acidification and intensive forestry. Planting products, in which sludge can be used in a proper amount to achieve a good nutritional balance for plants, is another alternative way for the use of sludge. This plant ground (area) can then be used for the construction of golf courses, and in various types of landscaping projects, for example noise fields or in the plant foundation layer for the coverage and restoration of waste dumps and different types of landfills.

Combustion with energy recovery: Dried or dewatered sludge can be burned separately or with biofuels or waste. Sludge can be used in the production of products such as precipitation chemicals, concentrated and clean fertilizer products from hydrolyzed sludge, and ash after sludge combustion. Sludge that has undergone some pretreatment, such as composting, is an exception of the ban on landfill disposal (Börje Andersson- wastewater department Personnel., Klippans Kommun, Sundin., 2017).

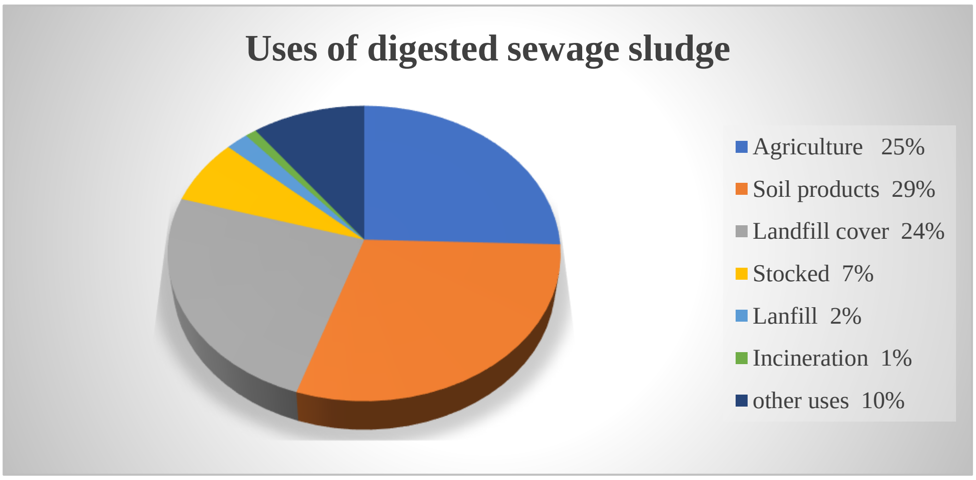


Fig 7. Digested sewage sludge uses in Sweden, 2014. Adapted from Sundin., 2017.

3.0 Legislative framework and permitting procedures for biogas installations

The legislation concerning biogas projects in Sweden addresses a range of aspects, such as environment, emergency management, technology, animal by-products, nature conservation, infrastructure, district planning, etc. (Scandinavian Biogas handbook, Aspects of planning a biogas plant, 2014). In Sweden, the national, regional and the municipal authorities are involved in the approval process of a biogas installation with respect to different aspects. Municipal authorities handle aspects concerning spatial planning, neighbours, building and techniques. The municipality handles the primary inquiry of safety related issues but further inquiries and final decision making are done by the national authority. Where specific parameters are exceeded; for example, large gas production capacities and animal by-products, the national authority takes charge. The owner of the biogas plant is responsible for the coordination, approval and control of the biogas installation. The owner of a plant usually involves the different authorities in planning and organising the project from the beginning, to ensure an optimised process, and to gain the support of the local politicians.

The government has put in place a series of guidelines which must be followed to acquire a permit to operate a biogas plant. Among these is the guidance of environmental testing of biogas plants, requiring the proprietor or the owner of the plant to show how much of biogas he intends to produce, nature of the substrate(s) and respective proportions, an outline of the advantages for which they are the best choices and, the source of the substrates. Any changes in the substrate streams, other than those listed during the application, must be notified to the supervisory authority to assess their potential environmental impacts. He must further show how digestate will be stored to avoid methane and nutrient leakages. This is contained in a document called *"Växtnäringsförluster, miljömål och åtgärdsprogram"* which means, nutrient losses, environmental goals and action plans. The proprietor is required to outline his strategy of bio-manure management, wherein a detailed description of how he intends to use the bio-manure is stated, as well as the storage and the transportation to the area of use. A more detailed description of the function of each guideline is found in the application documentation (Steinwig C. et al. 2013, www.msb.se).

The owners of farm-biogas installations must carry out analyzes of nitrogen and phosphorus content of bio-manure at least once a year, while those of co-digestion plants must do the same analysis at least four times a year, and the recipient(s) of bio-manure must be informed of the results of the analysis (Steinwig C. et al. 2013).

3.1 Application of Environmental code

Farmers who operate plants with biological treatment of waste: if the amount of manure and bio-manure (digestate) is greater than 500 tonnes per year, or less, they are always required to apply for environmental code B or C, respectively. The License application must be in writing, and containing (among others) information, drawings and technical descriptions needed to access the nature and the extent of the operation or measure; information on how the general rules of consideration in the environmental code have been met; suggestions for the safeguards or other precautions that are needed to prevent (or manage) any inconvenience caused by the operation; an environmental impact assessment; and proposals for checking the operation (Eskilsson J., 2013, Christensson K. et al., 2009).

3.2 Self-control

It is a system which is adapted to the environmental risk of the business to prevent environmental damage or damage on human health. Anyone who operates activities that can cause inconveniences to people's health or the environment is subject to self-assessment. Also, self-control does not only keep the owner informed of his activities' impact on the environment but also a way for the company to plan and organize work to counteract and prevent damage to the environment or human being's health. The farmers find out through self-check, that they are following the provisions and show to the regulatory authority that they know how to do it. A self-control exercise can be summarized by the following four steps which can always take place in parallel:

- Plan your own-control work regarding environmental impact.
- Perform control of operations.
- Follow the result of the check, and

- Improve control (Eskilsson J., 2013, Christensson et al., 2009).

3.3 Supervisory Authority

It is the environmental organ of the municipalities that carry out environmental surveillance over agriculture, except for animal husbandry activities, which are monitored by the administrative board. The board, however, can delegate powers to the municipality to do the monitoring. The supervisory authority controls that operations comply with the Environmental Code's requirements, as well as regulations and decisions taken from the Environmental Code. The supervisory authority shall also provide advice and information, as well as create conditions for achieving good environmental quality (Eskilsson J., 2013).

3.4 Cross Compliance

To get the full payment of farmer's support, farmer will have to meet the so-called cross-compliance; which states that:

- Farmer must follow certain rules that are available to achieve positive effects in e.g. the areas of environment and plant protection. This is called operational requirements.
- Farmer must handle all their farmland so that it is kept in good condition and that the farmland is managed in an environmentally friendly manner. This is called a maintenance requirement.

For agriculture in sensitive areas under the Nitrates Directive, several of the provisions are on storage and spreading of manure and bio-manure; cross compliance for the area and animal based supports (Eskilsson J., 2013). These regulations also apply to the spreading of digestate and digested sewage sludge as sub-classes of organic fertilizer. The limits of P and N application on arable land are the same as for manure (IEA bioenergy task 37).

3.5 Sanctions

Violations of regulations in the Environmental Code, provisions or rules, may lead to environmental sanctions or punishment in the form of fines or imprisonment, if convicted. The environmental sanction fees for violations of fertilizer management regulations and eco/green mark is between 1000 SEK (~€ 100) and 50,000 SEK (~€ 500). After a certain period, the fine can be repeated and increased to multiple folds (depending on the size of the farm) if the violation has not been terminated or the situation taken care of. Violations of the provisions that are in cross-compliance for the farm can also result in deduction of farm support.

3.6 Certification of digestate

Ecological food, and by extension ecological farming, is gaining popularity in EU and in Sweden. This increases the demand for certified biofertilizer (Facts and figures on organic agriculture in the European Union, 2013).

The certification of both liquid digestate and solid digestate in Sweden per SPCR 120 is optional and handled by RISE (Research Institute of Sweden) and its subsidiaries SP and JTI. SPCR 120 are certification rules, containing quality requirements for certified reuse of digestate from biogas production.

If SPCR 120 requirements are met, SP (Technical Research institute of Sweden) offers manufacturers permission to mark their products with the quality label "Certifierad Återvinning"; meaning certified for reuse (SPCR 120 Certifieringsregler för Biogödsel, SP Technical Research Institute of Sweden Certification, Januari 2009). The purpose of the Certification system is to increase reliability from an independent third party and create a market with high quality products. The presentation of product content and instructions for use of the digestate are also regulated (SPCR 120 Certifieringsregler för Biogödsel, SP

Technical Research Institute of Sweden Certification, Januari 2009; Eriksson. L & Runevad D., 2016). Today, 70 % of all digestate produced in co-digestion plants and used in agriculture, is certified (Avfall Sverige, 2016). For an overview of SPCR 120 document, please see appendix 1. The nutrient content of biofertilizer varies from different plants depending on the raw materials digested, the type of process digestion and how the process works. Biofertilizers contain nutrients and trace elements found in raw materials. What goes away during the process is the easily digestible carbonaceous material (http://www.biogodsel.se/vaxtnaring/).

Table 10. Nutrient content in SPCR 120 certified digestate. Data analysis from 18 co-digestion plants in 2014. Raw materials consisted of 35% industry food waste, 24% source sorted food waste, 23% manure, 12% slaughterhouse waste and 6% others.

	TS content (%)	Tot-N (Kg/ton)	NH4-N (Kg/ton)	Tot-P (Kg/ton)	Tot-K (Kg/ton)
Mean	3,9	5,2	3,3	0,7	2,0
Median	3,6	4,5	2,8	0,5	1,5
Max	8,3	23,2	16,6	3,3	11,6
Min	1,1	0,8	0,5	0,1	0,4

In the case of digested sewage sludge; the cooperation between stakeholders in agriculture, food industry, retailers and sludge management has led to a certification system called REVAQ with the slogan: “Clean water for better sludge.” The certification aims at improving sludge quality to guarantee safe reuse of sludge and to meet the demands from agricultural and food producer markets (Mattsson A. et al, 2012). The REVAQ trademark may be used by certificate holders for information and advertisement about upstream work. It may only be used on the product description of the sludge meeting the requirements for spreading to arable land (REVAQ regler för certifieringsystemet, 2017). Today, certified digestate is accepted by all Swedish food industries or associations as fertilizer. Even the Swedish organic food certification system KRAV accepts certified digestate to be used as fertilizer, if the substrates follow what is accepted according to the EU directive for ecological production. That is, slaughter house waste is not accepted but source separated organic household waste is accepted by KRAV (Avfall Sverige, 2016). Based on the acceptance of well sorted organic household waste that could contain micro plastics, there is routine follow up of separation procedure/techniques by landlords in collaboration with the municipal authorities. It is currently unclear exactly how microplastics affect nature, but it is known that these can be taken up by different animals and organisms, such as plankton and mussels, if they come into the sea (Blomquist, 2014).

The figures in the table below are the certification marks of digestate from farm and co-digestion plants and digested sewage sludge from WWTPs.

Certifierad Återvinning

REVAQ Certification

Fig 8. Trademark certification of digestate and digested sewage sludge from biogas co-digestion plants and wastewater treatment plants respectively.

Table 11. Guidelines of maximum metal content in digestate certified per SPCR-120 (SPCR 120 Certifieringsregler för Biogödsel, SP Technical Research Institute of Sweden Certification, Januari 2009)

Metal	**Max. content, mg/KgTS**
Lead	100
Cadmium	1
Copper	600
Chromium	100
Silver	1
Nickel	50
Zinc	800

3.7 Reduction of nutrient leakages

Many activities in agriculture and forestry risk harming or disturbing the environment, thus, consideration is necessary in such activities. Regulations regarding the environment are gathered in Environmental Code, and its ordinances. For certain activities and measures, there are clear rules in the legislation, and for others the rules are of a more general nature. Whether there is detailed legislation concerning certain measures, the Environmental Code's general rules of consideration always apply.

In brief, they state that *"every person who carries out, or intend to carry out, activities on the soil must obtain the knowledge and take the measures necessary for protecting human health and the environment against damage or inconvenience"*. More detailed rules about the handling of plant nutrients are available in the Ordinance (1998:915) on environmental concern in agriculture, and in the Swedish Board of Agriculture rules and general guidance (SJVFS 2004:62) on environmental concern in agriculture about plant nutrients.

The Ordinance on environmental concern in agriculture includes rules on manure storage capacity and minimum shares of land under vegetative cover during autumn or winter (so called green land) (www.jordbruksverket.se).

The Swedish Board of Agriculture rules and general guidance on environmental concern in agriculture, includes rules on covering of slurry stores, and filling of stores under a cover, rules on spreading area and other aspects of spreading, restrictions on applied quantities of manure and bio-manure, as well as detailed rules on green land.

3.8 Restrictions on applied quantities of manure, bio-manure and fertilizer.

The spreading of manure and other organic fertilizers is limited by its content of phosphorus. The supply of phosphorus from manure and organic fertilizers (digestate for example) may not exceed 22 kg per hectare available land, counted as a five-year average.

Within nitrate vulnerable zones (Stockholm, Södermanland, Östergötland, Kalmer, Blekinge, Skåne, Halland and Västra Götaland), manure and organic fertilizer may not be applied in quantities larger than the equivalent of 170 kg nitrogen per hectare available land and year. Furthermore, the supply of nitrogen via manure and fertilizers may not exceed the quantities considered necessary for the crop in the site in question. That is 22 kg of phosphorous is maintained everywhere in the country while the amount of nitrogen may vary depending on the crop needs (www.jordbruksverket.se).

In terms of nutrient accumulation, there may occur a certain degree of accumulation in some parts of the nitrate sensitive region, but there are fertilizer spreading rules that makes it all manageable (see below). The rules determine how much P can be spread per hectare and year, as also stated in Ch. 3.3. They also regulate, among other things, the fertilizer's content of cadmium per kilogram of phosphorus (Christensson K. et al., 2009).

3.9 Action plan against nutrient losses

Sweden's actions against plant nutrient losses and eutrophication are based on EU directives, international commitments and the environmental quality objectives adopted by Sweden.

The measures to reduce plant nutrient losses from agriculture are carried out via:

- Legislation (see chapter. 3.2)
- Financial instruments (Agri-Environmental payments, Non-productive investments)
- Extension services and information, for example through Focus on Nutrients (www.jordbruksverket.se).

3.9a Storage of manure and digestate

Manure shall be stored in a way that minimizes the risk of contamination of surface and ground water. This storage must be designed in a way that it prevents runoff or leaching to surrounding areas. Rainwater that runs off from manure facilities is regarded as manure, or as contaminated water, and must be collected and stored.

There are requirements regarding manure storage capacity for all agricultural enterprises with more than ten livestock units. In the nitrate vulnerable zones, storage capacity requirements apply to all enterprises with more than two livestock units. An enterprise shall be able to store manure for at least six to ten months before spreading, depending on which part of the country is concerned and what species the manure comes from.

3.9b Covering and filling of slurry stores

To prevent ammonia losses from the stored slurry, the air directly above it must be prevented from circulating. A method that efficiently reduces ammonia losses is to cover the slurry stores with, for instance, a roof, a floating plastic cover or a stable natural crust. In the south of Sweden, and in parts of the plains in central Sweden, special requirements regarding the filling and covering of slurry stores apply to agricultural enterprises that keep livestock (www.jordbruksverket.se).

3.9c Spreading of fertilizer and digestate

The rules on precautionary measures when spreading fertilizers are not the same in all parts of Sweden. In the nitrate vulnerable zones, the rules are more far-reaching than in the rest of the country. There are also specific rules which only apply in the counties of Blekinge, Skåne and Halland (www.jordbruksverket.se).

To minimize ammonia losses during spreading, mineral fertilizers (based on urea) that are spread on bare soil shall always be incorporated into the soil within four hours of the spreading. This rule applies in all of Sweden.

Manure and organic fertilizers that are spread during the period 1 December – 28 February, outside the areas identified as vulnerable, shall be incorporated into the soil within 12 hours.

In the counties of Blekinge, Skåne and Halland, manure that are spread on bare soil shall be incorporated into the soil within four hours. This applies during the entire year. With regards to the nitrate vulnerable zones, the following precautionary measures apply:

- Fertilizers may not be spread on water-saturated or flooded ground.
- Fertilizers may not be spread on frozen or snow-covered ground.
- Fertilizers may not be spread on agricultural land closer than two meters from an edge adjacent to a watercourse or a lake. Fertilizers may not be spread on agricultural land adjacent to a watercourse or a lake where the slope exceeds 10 %. Manure produced by animals themselves when outdoors, should not be counted in the term spreading.
- No fertilizers may be spread during the period 1 November – 28 February.
- During the period 1 August – 31 October, manure and other organic fertilizers may only be spread on growing crops or before autumn sowing. Spreading in catch crops is not allowed.
- Solid manure (except from poultry) may however be spread on bare soil during the period 1 October – 31 October, even if the land is not about to be sown.
- Solid manure spread on bare soil during the period 1 October – 31 October shall be incorporated into the soil within four hours in the areas identified as vulnerable within the counties of Blekinge, Skåne and Halland. For other areas identified as

vulnerable, rules apply that solid manure spread on bare soil shall be incorporated into the soil within 12 hours during this period (www.jordbruksverket.se)

3.9d Spreading liquid manure in growing crops

The largest part of ammonia losses due to the spreading of manure takes place in the first hours after spreading. This means that if the manure is quickly incorporated into the soil or placed directly into the ground, the losses are efficiently reduced. In the counties of Blekinge, Skåne and Halland, the spreading of liquid manure in growing crops shall be carried out using one of the following options that efficiently reduces ammonia losses.

- A method that places the manure directly on the ground underneath the green cover, for instance band spreading.
- Liquid manure drill or a similar method that places the manure directly into the ground.
- Any method that dilutes the manure with water before spreading (1-part manure and at least ½ part water).
- Spreading followed by irrigation supplying at least 10 mm of water. The supply of water shall begin no later than four hours, and be completed within 12 hours, after the spreading began. Rain counts towards fulfillment of the 10 mm requirement.

3.9e Rules concerning land under vegetative cover in the autumn and winter

During autumn and winter arable land is kept under vegetative cover (green land) especially where the soils are light with climate gentle to efficiently reduce plant nutrient losses. In the counties of Blekinge, Skåne and Halland, the rules state that 60 % of arable land shall be under vegetative cover during the autumn and winter. In the rest of southern Sweden, the requirement is 50 % (www.jordbruksverket.se).

3.9f Extension services

Extension services and information are important tools for achieving an improved plant nutrient management and to reduce the negative impact on environment. Extension services help to adapt measures brought up to local conditions and circumstances on the individual farm.

The Board of Agriculture employs plant nutrient advisors in Alnarp, Skara, Linköping and Uppsala. The regional offices coordinate advisory service in their respective parts of Sweden. They work to ensure that actions to reduce plant nutrient losses from agriculture are implemented efficiently. This means that regional activities in plant nutrients shall be run in a way that:

- adapts the use of plant nutrients to need, about cultivation,
- adapts feeding to needs,
- ensures that mineral fertilizers and manure are spread in a way that makes optimal use of the plant nutrients and avoids negative effects on the environment,
- stimulates the use of cropping systems and cropping techniques that combine financial profitability with minimal environmental effects,
- minimizes ammonia losses from agriculture.

Regional advisors shall spread information about results from research and trials in plant nutrients to the operators in the region, as well as other important information (e.g. legislation). Furthermore, they shall support other advisors in their work, and take part in various regional projects and studies within their special fields (www.jordbruksverket.se).

3.9g Focus on Nutrients

Focus on Nutrients (Greppa Näringen) is a joint venture (project) between The Swedish Board of Agriculture, The County Administration Boards, The Federation of Swedish

Farmers and a number of companies in the farming business which offers advice, free of charge, for farmers (http://www.greppa.nu, www.jordbruksverket.se).

Through Focus on Nutrients, agriculture is to contribute to the fulfillment of the Environmental Quality Objectives Zero Eutrophication, A Non-Toxic Environment, and Reduced Climate Impact.

Advisory service within Focus on Nutrients is procured by The County Administration Boards and provided by a variety of advisory firms. Farmers can choose between about 30 different advisory visits, which are divided by theme into "advice modules". At the initial advisory visit on the farm, the farmer and the advisor discuss the need of additional counseling and establish a nutrient balance for the farm. The nutrient balance shows the farm's starting position, and it is followed up one or several times during future visits. The farmer also receives a plan for the continuation of advisory visits, based on his/her own interests and the needs of the individual farm (www.jordbruksverket.se).

3.9h Information material

Brochures and other information material concerning plant nutrients and manure are produced by the Board of Agriculture on a regular basis. Several reports are published that are used as a basis for extension services and for monitoring compliance with the environmental legislation. Brochures and reports can be ordered from the Board of Agriculture's webpage www.jordbruksverket.se. Furthermore, the Board of Agriculture has designed computer software called Cofoten; as an aid for plant nutrient extension services focused on environmental issues. It can, for instance, be used for evaluating how various ways of handling manure affect the use of the plant nutrient content, or, for calculating plant nutrient balances at the farm (www.jordbruksverket.se).

4.0 Risk assessment of case examples of installations with potential adverse environmental impacts

4.1 Sweden's soil maps

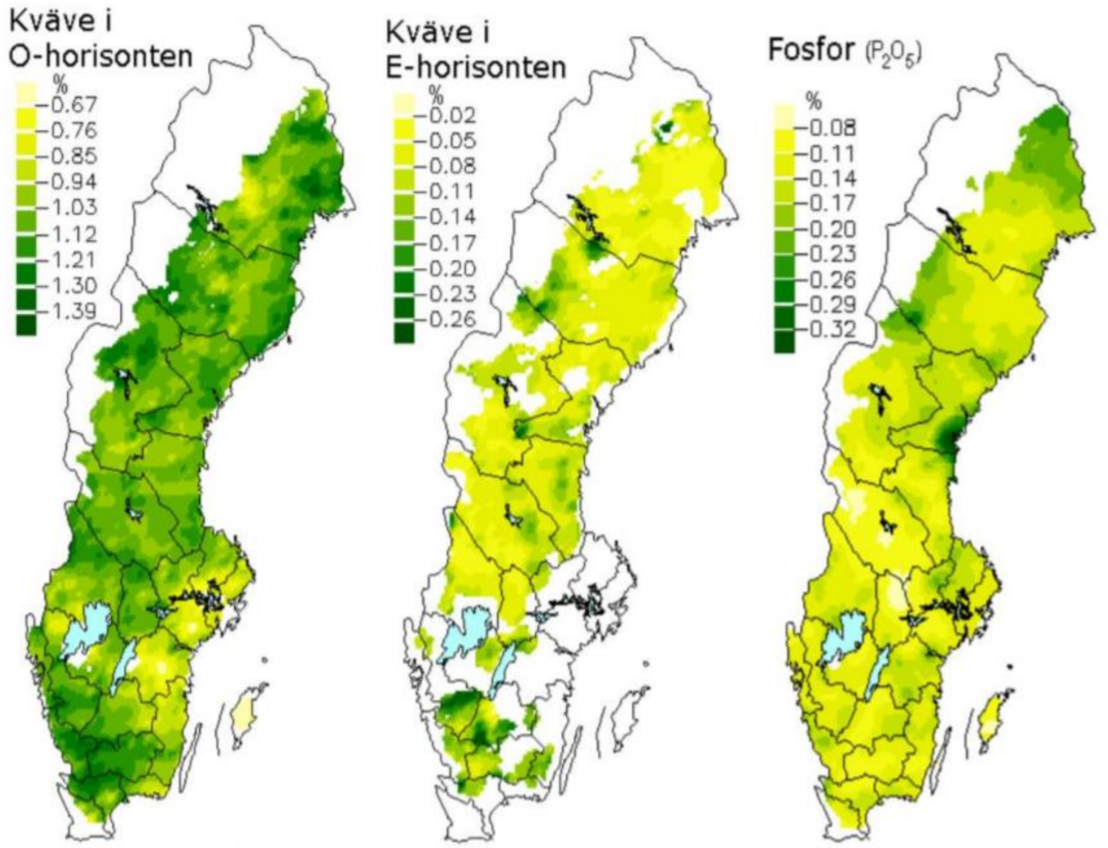


Fig 9. Mean content of N (map 1-O horizon & map 2- E horizon) and P (map 3) at 50cm depth in mineral soil. **http://www-markinfo.slu.se/sve/kem/**

Fig 12. Use of nitrogen (N) and phosphorous (P) from fertilizers and animal manure/digestate 2015/2016 adapted from Sverige officiella statistik.

		Crop area treated with nitrogen					Crop area treated with phosphorus				
County	Crop area 2016	Area,		N total[1]			Area,		P total		
	ha	%	se[2]	tonnes	kg N/ha[1]	rse[3]	%	se[2]	tonnes	kg P/ha	rse[3]
All of Sweden	2 394 400	76	0	196 080	107	1	63	1	29 370	19	1
Stockholm	69 500	69	3	4 680	97	6	48	4	550	17	6
Uppsala	145 800	80	2	12 300	106	3	64	3	1 610	17	5
Södermanland	112 600	68	2	9 060	118	3	52	3	1 120	19	6
Östergötland	190 100	76	1	15 910	111	2	52	2	1 930	19	5
Jönköping	84 400	84	2	6 030	85	5	80	2	1 530	23	4
Kronoberg	45 200	77	3	3 070	88	7	74	3	670	20	5
Kalmar	115 600	86	2	11 120	111	3	71	2	1 780	22	3
Gotland	82 100	86	1	6 840	97	3	75	2	1 030	17	3
Blekinge	29 200	87	2	2 620	103	5	56	4	350	21	5
Skåne	427 700	88	1	49 930	132	1	69	1	5 900	20	3
Halland	104 300	80	2	9 850	117	3	67	2	1 430	20	3
Västra Götaland	421 400	75	1	32 920	105	2	65	1	5 550	20	2
Värmland	94 500	60	3	4 980	88	5	56	3	860	16	4
Örebro	93 200	75	2	7 700	110	3	68	3	1 320	21	4
Västmanland	89 300	70	4	6 730	107	4	62	4	880	16	5
Dalarna	54 400	61	3	2 570	78	6	57	3	570	18	5
Gävleborg	62 200	59	3	2 760	75	5	50	3	550	18	6
Västernorrland	44 100	53	4	1 390	59	8	46	4	..	18	8
Jämtland	37 900	60	5	..	57	11	55	5	..	20	7
Västerbotten	60 300	65	3	2 930	74	6	53	3	..	18	5
Norrbotten	30 600	65	5	1 440	72	7	57	5	..	21	7

1) Plant available nitrogen
2) se=standard error
3) rse=relative standard error (%)

Sveriges officiella statistik

Table 13. Risk of nitrogen leaking from arable land with mineral mixed organic soil

Adapted from http://www.naturvardsverket.se

Class	Humus layer depth(m)	TN Conc (%)	Calculated Nitrogen mineralization (kg/h year)	Description
1	1	< 0,25	< 250	Moderate risk for nitrogen leaking
1	0,5	< 0,5	<250	Moderate risk for nitrogen leaking
3	1	0,25-0,4	250-400	Large risk for nitrogen leaking
5	1	> 0,4	> 400	Much risk for nitrogen leaking

Table 14. Risk of nitrogen leaking from arable land with organic soil.

Class	Humus layer depth(m)	TN Conc (%)	Calculated Nitrogen mineralization (kg/h year)	Description
1	1	< 0,85	< 250	Moderate risk for nitrogen leaking
1	0,5	< 1,7	<250	Moderate risk for nitrogen leaking
3	1	0,85-1,35	250-400	Large risk for nitrogen leaking
3	0,5	1,7-2,7	250- 400	Large risk for nitrogen leaking
5	1	>1,35	> 400	Much risk for nitrogen leaking
5	0,5	>2,7	> 400	Much risk for nitrogen leaking

Adapted from **http://www.naturvardsverket.se**

Table 15. Risk of phosphorous leaking from arable land in Sweden's soils

Class	P-AL-class	P-AL (mg P/100g soil)	Description	Distribution (%)
1	I-III	< 8	Low risk for high P leaking	49
3	IV	8-16	Certain risk for high P leaking	34
5	V	>16	Meaningful risk for high P leaking	12

Adapted from http://www.naturvardsverket.se

From the table 13 above: only 12 % of the soil in Sweden with P-AL (soluble phosphorous) greater than 16mg /100g of soil, has the potential of causing meaningful risk if phosphorous leaks.

4.2 Nitrogen and phosphorus balances for agricultural land and agricultural sector in 2013

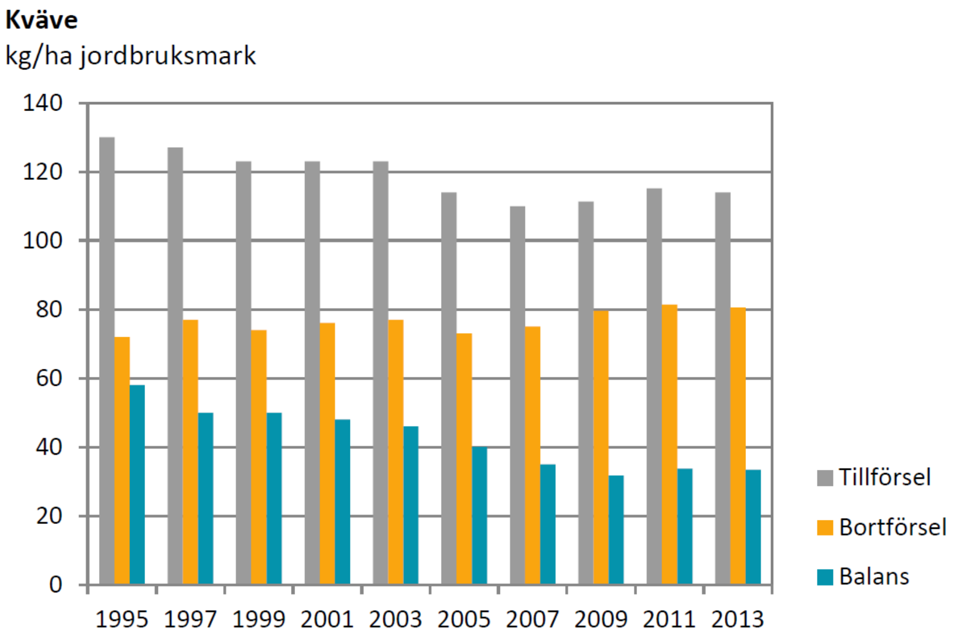


Fig 11; Input (tillförsel, output (bortförsel) and balance (balans), kg/ha, of nitrogen (kväve) for agricultural land in 1995–2013.

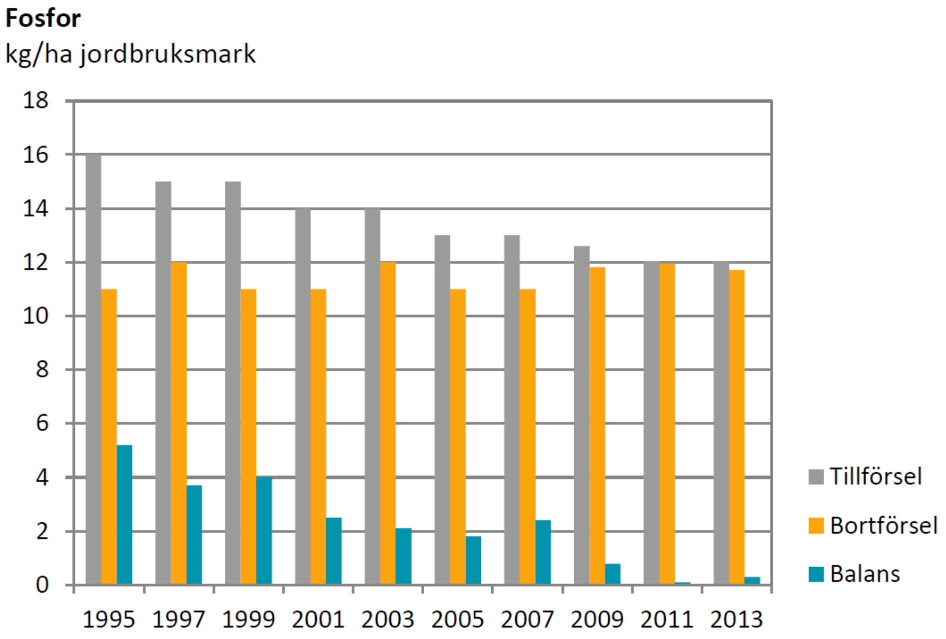


Fig12; Input (tillförsel, output (bortförsel) and balance (balans), kg/ha, of phosphorus (fosfor) for agricultural land in 1995–2013.

The graphs above are Sweden's nitrogen and phosphorus balances calculated for agricultural land in different regions for 2013 according to the soil surface gross method

(SCB MI 40 SM 1501, 2013). The method of calculation is partly adjusted to the method recommended by OECD and Eurostat (2007), starting from the balances of 2003. At national level, balances for the agricultural sector have been calculated according to the farm gate method (OSPAR, 1995) as stated in SCB MI 40 SM 1501, 2013.

According to the report, the following variables have been used in the soil surface method:

– **Nutrient inputs:** mineral fertilizer, soil amendments, stable and grazing manure, seed, atmospheric deposition, sewage sludge, digestate and biological nitrogen fixation.

– **Nutrient outputs:** yield and harvested plant residues.

The difference between nutrient inputs and nutrient outputs results in a soil surface balance that is either positive or negative. If positive, it shows a surplus. For nitrogen, it consists of ammonia volatilization from ventilation, storage and application, leaching, denitrification and built-up of the nutrient reserve in the soil. For phosphorus, the surplus consists of leaching and built-up of the soil nutrient reserve.

From the graphs above, it can clearly be seen that in Sweden, the input of nutrients through mineral and organic fertilizers as well as the surplus in nutrient balances has declined steadily over the past decade (Swedish Board of Agriculture).

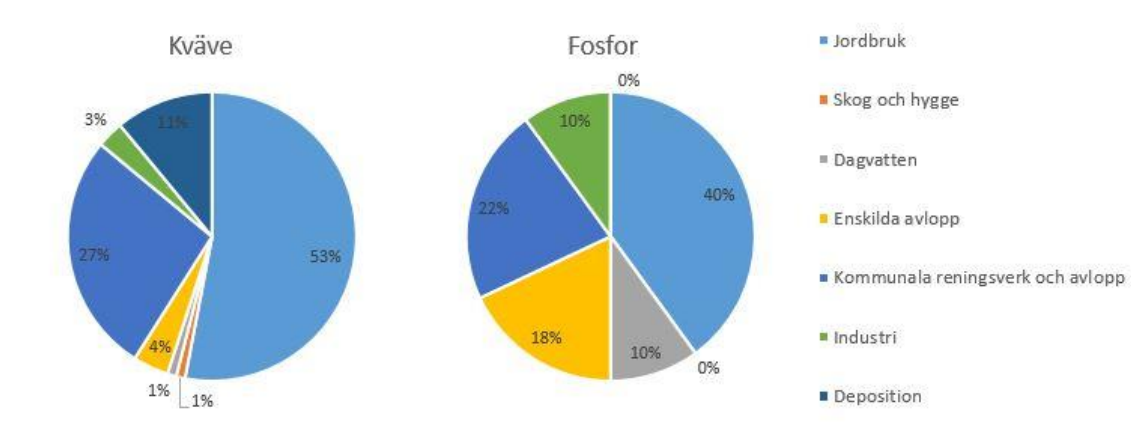


Fig 13. Different sources of human-related strain in term of nutrients (N & P) to the Proper Baltic Sea

The table below is a summary of how much digestate is produced from different types of biogas installations.

Table 16. Amount of digested sewage sludge and solid digestate produced by respective types of biogas installation, amount and % used as biofertilizer and the number of biogas plants certified by either REVAQ or SPCR 120 in 2015.

Type of Biogas plant	Production of digestate (tons wet weight)	Use of digestate as biofertilizer (tons wet weight)	Use of digestate as biofertilizer (%)	N0 of certified installations (REVAQ and SPCR 120)
Wastewater treatment	650 694	182 057	28	35
Co-digestion	1 710 412	1 689 834	99	19
Farm Installations	314 895	314 895	100	
Industrial Plants	10 576	0	0	0
Total	2 686 577	2 186 786	81	54

4.3 Risk assessment remarks for various biogas facilities.

After the holistic description of the situation of biogas in Sweden, in this section, possible scenarios through which nutrient leakages may occur in various facilities will briefly be discussed and remarks associated on whether there is any risk.

4.3.a Farm scale facilities

They produce good quality digestate ensued by the nature of the feedstocks and the AD process. Almost all the methane in the feedstock is extracted. Digestate is properly covered to avoid emission of ammonium. Digestate can only be applied seasonally on to the farms to avoid runoff. Its application is done by injection to ensure immediate uptake. Nutrient balances are performed by either the farmer himself or with the help of advisory firms like “Grippa näringen”. Farmers commend the use of digestate compared to raw manure or organic fertilizer.

On the bases of the visits I carried out and the literature upon which this report is written, there is no risk of nutrient leakages except on accident cases which have not been reported.

4.3.b Co-digestion facilities

They digest mixed substrate with organic material being the major component. Quality checks are carried out in the whole chain of collection of the organic waste and especially at the biogas plants. There are different strategies of these quality checks in different regions but the goal is the same. The liquid fraction of the digestate is recycled back into the digester while the solid fraction can easily be transported to farmers who are either co-owners of the facilities or pay a fee within 100 km. There is land ready for the application of digestate which is governed by regulations. Operators are advised to protect their facilities to avoid digestate spread in case there is a spillage. There is no risk of nutrient leakages and no accident cases have so far been reported.

4.3.c Wastewater Treatment plants

They are mostly involved in sludge reduction volumes. Effluent release into watercourses is regulated by EU Urban wastewater treatment directives and national regulations through set limits of N and P loads. Some situated in the North-East coast with low population and large water bodies may release effluents directly into the water courses. Those that are incorporated with biogas production voluntarily seek for REVAQ certification to increase the acceptability of digested sewage sludge. The proportion of digested sewage sludge used in agriculture is low. Depending on their uses, there might be risk of leaching.

4.3.d Industrial facilities

They are very few and are basically set up for the treatment of industrial wastewater coming from their operations. Until the Sweden's biogas statistic report of 2016 where it is stated that 62 % of the digestate from the industry is used as bio-fertilizer, digestate or residue emerging from these industries were basically sent to the wastewater treatment plants. The digestate is classified as digested sewage sludge from WWTP which are not REVAQ certified. As a result, the environmental impact of the digestate will depend on it's use. The regulations put in place in the management and application of digestate are sufficient to prevent nutrient management risks.

Calculations, example

- **SIA Bioenerģija-08**, 1 MW, substrates : manure (9600 T/year, 428 cattle) and grass, silage (48 000 T/year);
- 25 000 m3 digestate per year (63,7 T total N);
- Area for spreading according permission– 111 ha;
- Agricultural land - 520 hectars;

- 0,255 % total N= (170 kg/ha) - for area 375 ha.

From the example above (borrowed from the seminar), the amount of total nitrogen present in the digestate can be calculated.

25,000 m^3 digestate will produce 63.7 tonnes of Nitrogen

2186 786 tonnes of digestate = 918 450.12m^3 digestate, (http://www.traditionaloven.com).

918 450.12m^3 digestate = 918 450.12m^3 digestate ÷ 25,000m^3 * 63.7 tonnes N

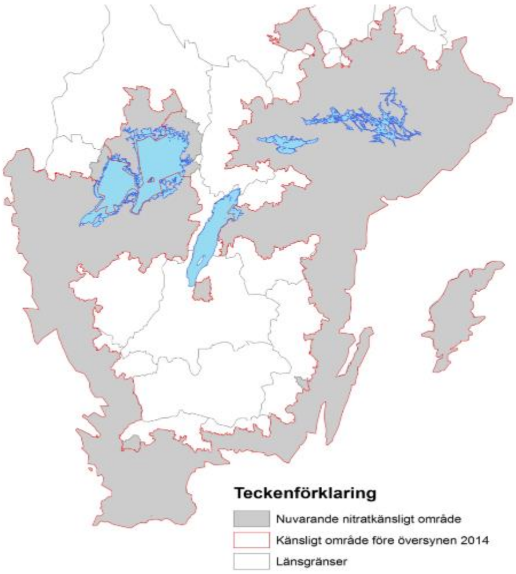
= 2,340.2 tonnes of total nitrogen.

According to the restrictions of applying bio-manure, the amount of nitrogen content may not exceed 170 kg/ha/year. This means that the total land needed to accommodate this amount of nitrogen will be 2,340,200 kg ÷ 170 kg = 13,765.8 hectares.

If 2,340,200 kg of total nitrogen is applied to 13,765.8 hectares, the plants will then take up how much they need in the form of nitrate and the rest are potential risk of leaching to any of the catchment areas of the Baltic Sea as shown by the following diagram.

4.4 Nitrates sensitive areas

According to the EU Nitrates Directives, the sensitive areas, which are reviewed every four years, led to further areas being added to the nitrate sensitive 2014 review. The map below is the region of the sensitive areas in Sweden. For these areas, there are further provisions to reduce plant nutrient losses from agriculture than in the rest of the country. The red line shows sensitive areas before the 2014 review and the gray areas are current sensitive areas.



As specified by Section 5, sub section 1, of the Regulation on Environmental consideration in Agriculture (Agricultural Agency's Regulations 2004: 62). The areas considered as nitrate sensitive are as follows: Stockholm, Södermanland, Östergötland, Kalmer, Blekinge, Skåne, Halland and Västra Götaland (Eskilsson J., 2013)

Fig 14. Map of nitrate sensitive areas in Sweden. Adapted from Eskilsson J., 2013.

Mitigation programs have been initiated in the agricultural sector to reduce nutrient losses (nitrogen and phosphorus concentrations discharging from arable land). To this effect there are two sub-programs within the Swedish Environmental Monitoring program to provide data to support the evaluation of mitigation programs. One focuses on water draining from individual arable fields (ca. 4-34 hectares in size), while the second is carried out at a larger scale, focusing on streams draining agricultural catchments ranging from 200 to 3500 hectares in size (www.slu.se).

4.5 Transportation of Digestate.

How far you can reasonably transport raw materials depends roughly on the energy content of the material per unit of weight. Even in case of pre-treatment, it is how well the material fits into the raw material mix. If you get paid to take care of the material e.g waste in the case of the municipality; the authorities are attracted to low cost. On the other hand, if the owner of a plant is to buy the raw materials, they are after energy content incentive. Thus, different economic parameters play a role. In the case of digestate transportation from biogas plant, there are readily available farmers especially those that supplied manure for the digestion to take care of the digestate. The biogas plant at Vårgårda is one that has a symbiotic relationship with its farmers within 100 km (Christensson K Skåne municipality., Olausson J. Biogas operative Vårgarda). Manure and certified digestate could be applied on the same arable land but there is always the precaution of not to exceed the limits as specified in the environmental code.

4.6 Accident Cases

Energigas Sverige (Swedish Gas Association) continuously gathers information about incidents and accidents involving any of the energy gases: natural gas, liquid petroleum gas (LPG), biogas, vehicle gas, hydrogen and liquid methane. The incidents and accidents reported span across for example, corrosion, material failure, wear, instrument or component failure, construction failure, assembly error, welding error, operational error, shaft error, crash or collision, fire, fire with gas, other causes, and unclear causes. Those reported under biogas segment in the latest biogas report (2015) are 4, although what happened specifically has not been mentioned. However, the table below gives information on incidents and accidents that occurred from the year 2000- 2012.

Table 17. Incidents and accidents reported within Biogas energy sector from 2000- 2012.

Date	Incident/accident	Personnel injury
04/04/2011	Gas heater to the gas dryer had melted the metal enclosure. Gas heaters are now replaced with new units through the security fence and alarm to the safety PLC	-
19/08/2011	Drill into the gas pipeline.	-
24/08/2011	Excavated biogas pipeline (high pressure).	-
12/09/2011	Damaged biogas pipeline (high pressure).	-
12/04/2010	Explosion in the room where slaughterhouse waste is sanitized before being used as raw material in Biogas process. It is likely that methane formed and for some reason ignited.	-
11/11/2010	Methane gas leakage in connection with manure handling in the farm. Fire fighters were consulted.	-
25/02/2009	Air holder meter exploded in the upgrading plant	-
09/04/2009	Foaming digester gave vigorous effervescence in edge pipe and gas pushed up through the water trap into the staff toilet in the digestion facility. The toilet and the control room were all gas filled. The stream was broken because of explosion risk and the rescue services were summoned.	-
07/05/2008	Biogas at a sewage treatment plant leaked out from a container where gas is stored in separate tanks. The lid of the container is lifted and the gas could be released.	-
30/05/2007	Leakage of gas (biogas) at 200 bar pressure is reported from 2 pipelines, 200m long. Leaks occurred around the heat affected areas around the welds.	-
10/05/2007	A large area of sewage treatment plant was blocked and later gas leak occurred in the plant. The leak seemed to have occurred from a pipe near the digester. The cause of the leak is not known.	-
01/06/2006	Leakage in a 4bar network. Cause unknown.	-
13/02/2006	Corrosion! Incorrect material. Stainless pipe.	
09/03/2005	A subscriber center leaked gas due to a pipe vibration caused by infrastructural damage. Gas spread through a wall where there was a fresh air intake.	-
26/01/2005	Biogas leakage at a biogas plant.	-
23/08/2004	A leakage of compressed air in the compressor at the gas cleaning sector in a biogas production plant. The reason was that a	-

	compressed air hose to have come loose when air pressure was on and the compressor was not in operation.	
12/06/2004	The filling valve to a biogas truck was leaking gas, probably because of poor parking. The main valve was closed.	-
22/02/2004	Motorist drove away with the hose after refueling. Break away connector did not lose as it should have and the dispenser overturned. No gas flowed out.	-
02/02/2004	Leaks in the furnace routes, which was not discovered in connection with the self-monitoring /inspection installation. The gas alarm was misplaced and therefore could not detect the fault immediately.	-
25/05/2003	A connection on the gas pipeline between the gas storage and the dispenser started leaking gas due to the combination of compression fittings and PV400 pipes.	-
24/09/2002	A ten-year-old stepped down into the silo of digestate.	-
18/08/2002	Fire in a treatment plant. The gas engine was suspected first but indications of the switch gear emerged.	-
08/01/2002	Gas leak because a shaft agitator got detached and feel into the biogas digester at a sewage treatment plant.	-
xx/xx/2002	Small explosion at a biogas plant. Intermittent operation, leading to condensation in the gas system and subsequent corrosion with loss of function. The cause of the explosion might have resulted from it.	-
19/03/2001	Fire in the sludge storage tank that is part of a biogas plant.	-
xx/xx/2001	Biogas supplied is not odorized	-
xx/xx/2001	Fire in a biogas plant, stirrer in the digester tank should have been replaced. The gas ignited and it took several hours before it was extinguished.	-
xx/xx/2001	Breakdown of the compressor due to moist air used to raise the pressure on the biogas.	-

Avfall Sverige utveckling, Report U2012: 17

It should be noted that the incidents and accidents reported in this report and its source are not directly relevant to the digestion facilities and its processes. They include among others, incidents related to distribution networks, vehicle fuel-refilling and at central subscription. However, from the background, the following risks can occur in the digestion plants.

- In case of extensive foaming in the digester, there may be a risk of gas leakage via pipes and water paths.

- Digestate that get stocked between shut-off valves risks causing uncontrolled pressure increase due to gas extraction. This can lead to pipe cracking, for example, regarding digestate pumps.
- Gas leakage has occurred from gas pipes that connect to digester.
- Gas leakage has also been caused by the shaft of a stirrer loosening and falling into the container.
- Smaller fires have occurred with electrical equipment, smoking and welding as potential ignition sources.

5.0 Subsidies and profitability (e.g. gate fees, electricity sold out) of production

Table 18. Use of biogas from 2005-2015 in GWh

Area	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Upgrading	112	218	303	355	488	608	734	845	907	1017	1219
Heat	687	678	732	720	667	606	562	524	521	434	387
Electricity	37	99	62	59	64	56	47	41	46	58	70
Industrial Use										75	49
Others											19
Flaring	122	158	195	195	135	112	115	165	186	191	198
Missing data	327	60	21	30	9	3	16	26	26	9	13
Total	**1285**	**1213**	**1258**	**1359**	**1363**	**1387**	**1473**	**1589**	**1686**	**1784**	**1955**

Biogas produced in Sweden can be used in various ways. It can be used for local heating (via district heating network) or to generate electricity, thus contributing to an increased proportion of 'green electricity' distributed through the grid. Biogas that has been upgraded, i.e. when the carbon dioxide has been removed, to a methane content of about 97 %, may be used as vehicle fuel. This presents a good alternative for petrol and diesel (Biogas in Sweden-Swedish gas association., March 2011).

5.1 Electricity Certificates

A support system based on electricity certificate was introduced in 2003 to encourage the production of electricity from renewable resources; biogas included (Swedish gas association 2011). In January 2012, Sweden went into corporation with Norway for a joint market for electricity certificates with the goal to develop new energy production, based on renewable energy sources in a cost-effective way, amounting to 28.4 TWh by the end of 2020. Sweden will finance 15.2 TWh and Norway 13.2 TWh (The Norwegian-Swedish electricity certificate market annual report., 2015). Based on this certificate system, producers receive one certificate for each MWh of electricity generated from renewable resources over a maximum of 15 years. The certificate can be sold which generate additional income for the producer. And at the same time, all electricity consumers (except for some heavy industrial consumers) are required to buy a certain proportion of renewable electricity by purchasing certificates. The cost of the certificates is distributed among the consumers. The price span for the year 2014/2015 was 140-190 SEK/MWh (~15-20 €) (Biogas in Sweden - Swedish gas association., March 2011, IEA Bioenergy task 37, 2015). The municipality always pays a fee to the biogas plants for handling waste where the substrate is manure. Sometimes the farmers are co-owners of the plant and therefore get the digestate for free. If the raw material is energy crop, e.g ley crop as it is the case at Växtkraft biogas AB in Västerås, the plant pays for the substrate (ley crop) and the farmers in turn pay a fee for the digestate.

5.2 Investment support - agricultural program

In 2009, an investment support for farm-based biogas production and industrial production for the marketing of new technologies and new solutions for biogas was introduced by the government. Farms and other rural businesses investing in biogas production receive a maximum support of 35 %, while industrial or large-scale plants receive a maximum of 45 % or 25MSEK (~3 M€), of the investment costs. This investment support is included in the rural development program and comprises 200 MSEK (~21 M€) for the period 2009-2013 with an extension. However, the conditions imposed by the program are, that manure represents at least half of the substrate digested, and that the digestion residues are stored leak-free (Biogas in Sweden - Swedish Gas Association., March 2011, IEA Bioenergy task 37, 2015).

5.3 Super-environmentally-friendly car premium

A 'super-environmentally-friendly car premium' worth 40 000 SEK (~ 4100 €) was announced by the Government in 2011. It can be paid out for cars with carbon dioxide emissions of less than 50 grams/km, which will mostly be relevant for electric cars and the best gas-driven cars. In 2011, it was estimated that 5000 cars will be covered by this program in the next four years, which will cost the Treasury about 200 million SEK (Biogas in Sweden - Swedish Gas Association., March 2011).

5.4 Dispensation from traffic tolls for environmentally-friendly cars

In the Swedish capital (Stockholm), environmentally-friendly cars have been given dispensation from traffic tolls to promote their use. This dispensation is valid for cars bought after 1 January 2009, and will cease completely for all environmentally-friendly cars from 1 August 2012 (Biogas in Sweden - Swedish Gas Association., March 2011).

5.5 Climate investment grant for municipalities

There are climate investment grants for municipalities with a total budget of 1,925 MSEK (~200 M €) until the end of 2018. This is like KLIMP, the development of new biogas plants supported by central Government funding through local climate investment programs (IEA Bioenergy task 37., 2015, BiogasinfoEngGodaExampel- Swedish Gas Association).

5.6 No carbon dioxide or energy tax on biogas

The government announced that there will be no carbon dioxide or energy tax on biogas until the end of 2015 (extension 2020 pending EU approval). Corresponding to around 708 SEK/MWh (76 €) compared to petrol, and 570 SEK/MWh (61 €) compared to diesel (IEA Bioenergy task 37., 2015).

5.7 Reduction of income tax by 40% for company natural gas vehicles (NGVs)

Income tax has been reduced for company vehicles running on natural gas by 40 % until the end of 2019, amounting to a total of 10,000 SEK (~1000 €).

Biogas produced from manure is subsidized by 0,2 SEK/KWh (~0,02 €/KWh) to reduce methane emission from manure. A total budget of 355 MSEK has been allocated to cover a period of 10 years (IEA Bioenergy task 37., 2015).

6.0 Case examples (if any) of commercial products from digestates

A market analysis was carried out in Sweden on biogas digestate to provide valuable information regarding the current market for digestate, as well as to find out new potential areas of its application. The approach of the study was to present a review of other reports, complementing with interviews from different stakeholders, such as biogas plants.

The result showed that digestate is mainly used in agriculture as a soil improver and, that this will probably be the main market in the future as well. However, the operators at the biogas plants could see a development of digestate use in areas such as horticulture and landscaping (Eriksson L. & Runevad D., 2016).

During the study, another report was reviewed that aimed at comparing the whole digestate, liquid fraction and solid fraction with commercial fertilizers. Results presented two promising areas for digestate use; one was co-composting the solid digestate with woodchips, creating a product that could be suitable for landscaping and urban forestry. Another was the use as a multi-purpose growing media, for example gardening (Eriksson L. & Runevad D., 2016). Rigby and R Smith (2011) as stated by Eriksson L. & Runevad D., 2016, also concluded that peat is a finite resource and other composting products could be interesting as replacement.

Case examples of commercial products of biogas digestate certified by SPCR 120 are simply called Biogödsel (bio-manure or bio-fertilizer).

In addition, GASUM, a Finnish biogas and biofertilizer producing company with its headquarters in Finland, has four establishments in Sweden where biogas and biofertilizers are produced. Recently it is thought that GASUM has bought over Biogas Sverige International renamed as GASUM AB. The biogas is mainly produced from locally produced, crop-based raw material. It uses grains, oil seeds and peas among the varied substrate group. The bio fertilizer is rich in both nutrients and humus. The solid product ensues from the separation of the liquid bio-fertilizer produced in the digestion process. The product is approved according to the requirements for RISE certification for biofertilizer, SPCR 120, as well as allowed to be use in KRAV-certified ecological production. These four establishments of bio-manure production are known as biogödsel Örebro, biogödsel Lidköping, biogödsel Västerås and biogödsel Jordberga (www.Gasum.com).

7.0 Case examples (if any) of circular economy, where biogas is a part of a larger chain

The Ellen McArthur foundation (2015) defines circular economy as stated in Hagman L. & Eklund M., 2016 as restorative and regenerative by design, and aims at all times to keep products, components, and materials at their highest utility and value. The concept thus implies circular flows considering aspects like the value and quality of what is being circulated.

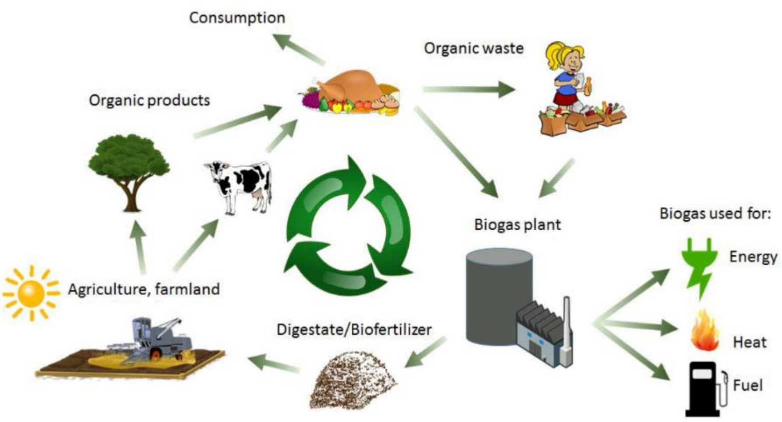


Fig 15. Biogas carbon chain illustrating nutrient recycling and circular economy

Aquaculture requires energy input which is used to power the pump installations and to heat the basins in wintertime. By inference therefore, the 387 GWh of heat produced is likely used for the mentioned reasons.

Fish processing wastes are also suitable for biogas production. However, these materials would be added as a co-substrate to boost the biogas production of plants treating agricultural or municipal wastes. They cannot be used as the main substrate due to the inhibitory effects of long chain fatty acids and high protein concentrations.

There are two case examples where Biogas plants are connected to the fishing industry in Sweden. A few months ago, a company called “Rena hav” (renahav.se) just got its permit for this business and they will fully be in operation from next year (Gunnarsson Bengt-CEO).

As illustrated in the diagram below, large amounts of fish processing waste from the fish industry in Sotenäs is received and mixed with co-substrates including sewage sludge (in the industrial area where transportation is not required). The mix is then digested and biogas is produced. The gas is then fed into a generator to produce electricity and heat which is returned to the fish industry to heat the basins and power the pumps. The resulting digestate is certified and used by farmers for ecological farming. Process water from the fish basins is sent to the waste water treatment plant where it is cleaned and purged into the sea (Rena hav.se).

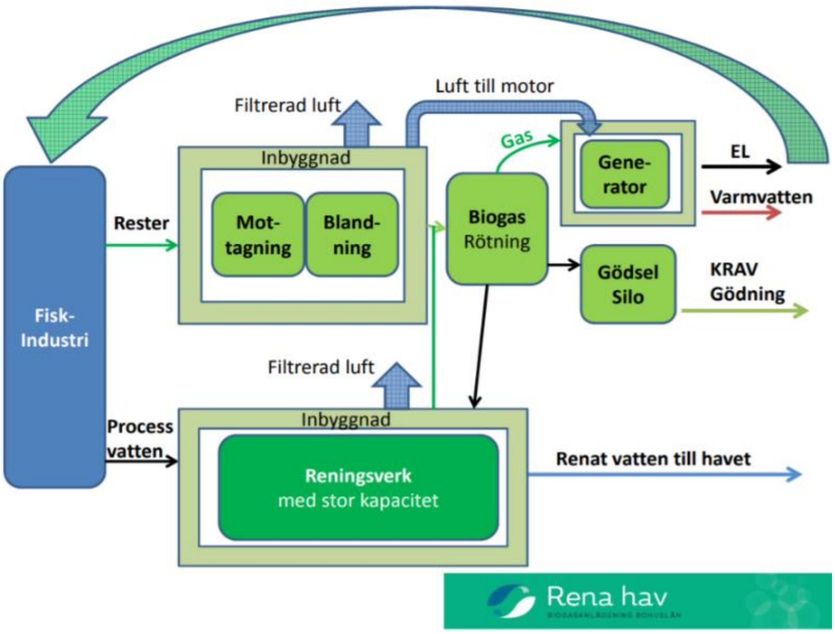


Fig 16. Circular economy of biogas production by Rena hav. Adapted from Rena hav, energi och växtkraft.

8.0 Proposals for mitigating adverse environmental impacts of biogas production

Based on environmental and sustainability goals that Sweden has set, biogas production is likely to increase. No incidents regarding negative effects of digestate have been recorded.

More research should be carried out on digestate and digestate products that are easily transported, including the possibility of drying-making pellets as biomass which in turn could be used for incineration to produce energy. As a proposal of dealing with nutrient leakages, "Grippa näringen" suggest mandatory reporting of nutrient balances by the farmers, but also noted that it should be done with flexibility as it may risk imposing focus on figures rather than a more profound understanding.

The authorities should develop more inclusive strategies of information campaign to increase the acceptance of certified digestate.

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Appendix 1. Summary of SPCR 120 – Certification rules for digestate from bio-waste by the quality assurance system of Swedish Waste Management (December 2007).

Anneli Petersson, Swedish Gas Centre - 2008.

This is **not** a complete translation of SPCR 120, but should be seen as an overview of the SPCR 120 document.

Substrates for certificated digestate should be clean, source separated and easily biodegradable (of the types shown in Tab.1). Only approved additives and process chemicals may be used (see Tab. 2 and Tab. 3). Before digestate from a plant can be marked with the quality label it has to pass a qualification year. The qualification year starts when an un-objective authority takes its first sample at the plant. To pass the qualification year, both the plant's own samples (for sample frequency see Tab. 5), and the samples taken by the authority must passed the test (for analysis see Tab. 6). All documentation must be in order (e.g. process parameters that must be documented, see Tab. 4). The qualification year starts over if samples do not pass the test and if no satisfying explanation can be found and the problem cannot be solved. After a passed qualification year, digestate produced during the qualification year can be labeled, as well as new digestate produced on the plant. During the qualification year there is also a hygienization control which is repeated every 5 years (depending on the utilization of the digestate). The certificate is valid for 5 years.

The labeled product may not contain higher metal concentrations than specified (see Tab. 7), the labeled digestate should include declaration of content (see Tab.8), guide of how to use it, testing report and a process description. Depending on types of substrates and utilization of the digestate, hygenization control and bacteriological testing of the digestate have to be done and passed (for sample frequency see Tab. 5).

Visible contaminants (> 2mm) may not be more than 0.5 weight% of DM. For solid digestate there may not be more than 2 germinative seeds / liter and the organic substance must be more than 20 %. The un-objective authority visits the plant 1-2 times per year (depending on plant size). Samples are taken and the plant's own control is checked.

Substrates for certificated digestate.

Source	**Example**
Parks, gardens, etc.	Leafs, grass, branches, fruit, flowers, plants and parts of plants.
Greenhouses, etc.	Tops, soil, peat products.
Households, kitchens, restaurants[1]	Fruit and vegetables remainders, coffee and tea remainders, remainders of food, egg shells, cardboard, paper, paper bags, biodegradable bags, plants och flower soil. Bags for source separated house hold waste should fulfill EN 13432 from 1/1 2005.
Food related shops[1]	Fruits, vegetables, potatoes, diary waste, paper towels, paper napkins, bread, meat, meat parts, charcuterie parts, flowers, plants, soil and peat. Food containing additives allowed for food production are allowed in the substrates.
Food industry[1]	Remainders from food industry that contains additives allowed I food production are allowed as substrates.
Agriculture[1]	Manure, straw, by-products from harvesting, ensilage, energy crops.
Forrest	Bark, wood chips, fiber sludge from the cellulosic industry.
Animal by-products, category 2	Only manure, content stomach and intestine separated from stomach and intestine, milk and raw milk.
Animal by-products, category 3	See ABF

[1]If the substrate contains animal by-products regulation for this should be followed

Additives and process Chemicals

Allowed additives

Allowed additives according to SPCR 120
Organic[1] or mineral fertilizers
Lime

[1]Animal by-products regulation for this should be followed

Allowed process chemical

Allowed process chemicals according to SPCR 120
Iron chloride
Iron oxide
Bentonite
KMB1
Diatomaceous earth

Process control. The following parameters should be measured and documented:

Types and amounts of substrates, additives and process chemicals
Temperature and pH in the reactor
Time between feeding of substrate
Hydraulic retention time
Time and temperature in the hygenization tank
Organic loading rate
Volumetric loading
Actions taken to avoid re-contamination
Process disturbances

Lowest allowed frequency of sample taking and analysis. Sample taking should be spread over the year.

	Samples per year taken by plant personnel			
Amount received of substrate for biological treatment /ton/year) received	Qualification year		After qualification year	
	Samples except bacterial sample	Bacterial sample	Samples except bacterial sample	Bacterial sample
<5000	2	4	1	4
from 5000	4	4	2	4
from 10 000	8	4	4	4

SPCR 120 also regulates how samples should be taken

Methods for analyses. Equal methods may be used if the same or better measuring accuracy can be reached.

Analyses parameter	**Method**
Metal content (Pb, Cd, Cu, Cr, Hg, Ni, Zn)	SS-EN 13346mod/SS11885-1
Visible contaminates	BGKII:10 1998:4
Germinative seeds and plant parts (only for solid digestate)	BGKII:9 1998:4
Dry matter	SS 12880
VS	SS-EN 12879-1
Total N	SS02801-1/SS-ISO 11261
Total P	SS-EN13346/mod SS11885-1
Total K	SS-EN13346/mod SS11885-1
N-NH4	St. Meth.16417A+D
Mg	SS-EN13346/modSS11885-1
S	SS-EN13346/modSS11885-1
Ca	SS-EN13346/modSS11885-1
pH	SS-EN12176
Microbial parameters[1]	
Esherichia coli	NMKL no 125, 2005, version 4
Enterococaceae	NMKL no 68, 2004, version 4
Salmonella	NMKL no 71, 1999, version 5

[1]These parameters should be measured by the NMKL methods stated in the table.

Maximal content of metals in the digestate

Metal	**Maximal amount (mg/kg DM)**
Pb	100
Cd	1
Cu	600
Cr	100
Hg	1
Ni	50
Zn	800

Declaration of content

Paramter	**Unit**
Tot. N	kg/ton and kg/m3
NH4-N	kg/ton and kg/m3
Tot. P	kg/ton and kg/m3
Tot. K	kg/ton and kg/m3
Mg	kg/ton and kg/m3
S	kg/ton and kg/m3
Ca	kg/ton and kg/m3
Organic substance	% of DM
pH	-
DM	Weight percent

Appendix 2 List of some Biogas plants in Sweden

Municipality	County	Type of plant
Alingsås	Västra Götaland	Sewage treatment plant
Alvesta	Kronoberg	Sewage treatment plant
Arboga	Västmanland	Sewage treatment plant
Arvika	Värmland	Sewage treatment plant
Askersund	Örebro	Sewage treatment plant
Avesta	Dalarna	Sewage treatment plant
Bjuv	Skåne	Sewage treatment plant
Bollnäs	Gävleborgs	Sewage treatment plant
Borgholm	Kalmar	Sewage treatment plant
Borlänge	Dalarna	Sewage treatment plant
Borås	Västra Götaland	Sewage treatment plant
Botkyrka	Stockholm	Sewage treatment plant
Degerfors	Örebro	Sewage treatment plant
Eksjö	Jönköping	Sewage treatment plant
Enköping	Uppsala	Sewage treatment plant
Eskilstuna	Södermanland	Sewage treatment plant
Eslöv	Skåne	Sewage treatment plant
Falkenberg	Halland	Sewage treatment plant
Falkenberg	Halland	Sewage treatment plant
Falköping	Västra Götaland	Sewage treatment plant
Finspång	Östergötland	Sewage treatment plant
Forshaga	Värmland	Sewage treatment plant
Gislaved	Jönköping	Sewage treatment plant
Gotland	Gotland	Sewage treatment plant
Gävle	Gävleborgs	Sewage treatment plant
Göteborg	Västra Götalands	Sewage treatment plant
Götene	Västra Götaland	Sewage treatment plant
Hagfors	Värmland	Sewage treatment plant
Hallsberg	Örebro	Sewage treatment plant
Hallstahammar	Västmanland	Sewage treatment plant
Halmstad	Halland	Sewage treatment plant
Haninge	Stockholm	Sewage treatment plant
Haparanda	Norrbotten	Sewage treatment plant
Hedemora	Dalarna	Sewage treatment plant
Hedemora	Dalarna	Sewage treatment plant
Helsingborg	Skåne	Sewage treatment plant
Hudiksvall	Gävleborgs	Sewage treatment plant
Hässleholm	Skåne	Sewage treatment plant
Hässleholm	Skåne	Sewage treatment plant
Hässleholm	Skåne	Sewage treatment plant
Höganäs	Skåne	Sewage treatment plant

Höganäs	Skåne	Sewage treatment plant
Höör	Skåne	Sewage treatment plant
Jönköping	Jönköping	Sewage treatment plant
Jönköping	Jönköping	Sewage treatment plant
Kalmar	Kalmar	Sewage treatment plant
Karlshamn	Blekinge	Sewage treatment plant
Karlshamn	Blekinge	Sewage treatment plant
Karlskoga	Örebro	Sewage treatment plant
Karlstad	Värmland	Sewage treatment plant
Katrineholm	Södermanland	Sewage treatment plant
Klippan	Skåne	Sewage treatment plant
Kristianstad	Skåne	Sewage treatment plant
Kristinehamn	Värmland	Sewage treatment plant
Kumla	Örebro	Sewage treatment plant
Kävlinge	Skåne	Sewage treatment plant
Laholm	Halland	Sewage treatment plant
Laholm	Halland	Sewage treatment plant
Landskrona	Skåne	Sewage treatment plant
Lerum	Västra Götaland	Sewage treatment plant
Lidingö	Stockholm	Sewage treatment plant
Linköping	Östergötland	Sewage treatment plant
Ljungby	Kronoberg	Sewage treatment plant
Ljusnarsberg	Örebro	Sewage treatment plant
Ludvika	Dalarna	Sewage treatment plant
Ludvika	Dalarna	Sewage treatment plant
Luleå	Norrbotten	Sewage treatment plant
Lund	Skåne	Sewage treatment plant
Lund	Skåne	Sewage treatment plant
Lund	Skåne	Sewage treatment plant
Lysekil	Västra Götaland	Sewage treatment plant
Lysekil	Västra Götaland	Sewage treatment plant
Malmö	Skåne	Sewage treatment plant
Malmö	Skåne	Sewage treatment plant
Mariestad	Västra Götaland	Sewage treatment plant
Mellerud	Skåne	Sewage treatment plant
Motala	Östergötland	Sewage treatment plant
Mönsterås	Kalmar	Sewage treatment plant
Nora	Örebro	Sewage treatment plant
Norberg	Västmanland	Sewage treatment plant
Norrköping	Östergötland	Sewage treatment plant
Norrtälje	Stockholm	Sewage treatment plant
Norrtälje	Stockholm	Sewage treatment plant
Nyköping	Östergötland	Sewage treatment plant
Nynäshamn	Stockholm	Sewage treatment plant
Oskarshamn	Kalmar	Sewage treatment plant
Perstorp	Skåne	Sewage treatment plant
Piteå	Norrbotten	Sewage treatment plant
Rättvik	Dalarna	Sewage treatment plant

Sala	Västmanland	Sewage treatment plant
Sandviken	Gävleborgs	Sewage treatment plant
Sjöbo	Skåne	Sewage treatment plant
Skara	Västra Götaland	Sewage treatment plant
Skellefteå	Västerbotten	Sewage treatment plant
Skövde	Västra Götaland	Sewage treatment plant
Smedjebacken	Dalarna	Sewage treatment plant
Sollefteå	Västernorrland	Sewage treatment plant
Sotenäs	Västra Götaland	Sewage treatment plant
Stockholm	Stockholm	Sewage treatment plant
Stockholm	Stockholm	Sewage treatment plant
Sundsvall	Västernorrland	Sewage treatment plant
Sundsvall	Västernorrland	Sewage treatment plant
Sundsvall	Västernorrland	Sewage treatment plant
Surahammar	Västmanland	Sewage treatment plant
Tibro	Västra Götaland	Sewage treatment plant
Tomelilla	Skåne	Sewage treatment plant
Tranås	Jönköping	Sewage treatment plant
Trelleborg	Skåne	Sewage treatment plant
Trollhättan	Västra Götaland	Sewage treatment plant
Uddevalla	Västra Götaland	Sewage treatment plant
Ulricehamn	Västra Götaland	Sewage treatment plant
Umeå	Västerbotten	Sewage treatment plant
Uppsala	Uppsala	Sewage treatment plant
Uppsala	Uppsala	Sewage treatment plant
Vadstena	Östergötland	Sewage treatment plant
Varberg	Halland	Sewage treatment plant
Vimmerby	Kalmar	Sewage treatment plant
Vingåker	Södermanland	Sewage treatment plant
Vänersborg	Västra Götaland	Sewage treatment plant
Värmdö	Stockholm	Sewage treatment plant
Värnamo	Jönköping	Sewage treatment plant
Västervik	Kalmar	Sewage treatment plant
Västerås	Västmanland	Sewage treatment plant
Växjö	Kronoberg	Sewage treatment plant
Ystad	Skåne	Sewage treatment plant
Åstorp	Skåne	Sewage treatment plant
Åtvidaberg	Östergötland	Sewage treatment plant
Älmhult	Kronoberg	Sewage treatment plant
Ängelholm	Skåne	Sewage treatment plant
Örebro	Örebro	Sewage treatment plant
Örkelljunga	Skåne	Sewage treatment plant
Örnsköldsvik	Västernorrland	Sewage treatment plant
Örnsköldsvik	Västernorrland	Sewage treatment plant
Örnsköldsvik	Västernorrland	Sewage treatment plant
Östersund	Jämtland	Sewage treatment plant
Östhammar	Uppsala	Sewage treatment plant
Östra Göinge	Skåne	Sewage treatment plant

Eslöv	Skåne	Industrial
Umeå	Västerbotten	Industrial
Örnsköldsvik	Västernorrland	Industrial
Bjuv	Skåne	Farm-based
Gotland	Gotland	Farm-based
Götene	Västra Götaland	Farm-based
Halmstad	Halland	Farm-based
Lerum	Västra Götaland	Farm-based
Luleå	Norrbotten	Farm-based
Malmö	Skåne	Farm-based
Nyköping	Södermanland	Farm-based
Boden	Norrbotten	Co-digestion
Borås	Västra Götaland	Co-digestion
Falköping	Västra Götaland	Co-digestion
Helsingborg	Skåne	Co-digestion
Huddinge	Stockholm	Co-digestion
Jönköping	Jönköping	Co-digestion
Kalmar	Kalmar	Co-digestion
Kil	Värmland	Co-digestion
Kristianstad	Skåne	Co-digestion
Laholm	Halland	Co-digestion
Linköping	Östergötland	Co-digestion
Skellefteå	Västerbotten	Co-digestion
Skövde	Västra Götaland	Co-digestion
Uppsala	Uppsala	Co-digestion
Vetlanda	Jönköping	Co-digestion
Vänersborg	Västra Götaland	Co-digestion
Vårgårda AB	Västra Götaland	Co-digestion
Västerås	Västmanland	Co-digestion
Älmhult	Kronoberg	Co-digestion