NUTRIENT MANAGEMENT AT BIOGAS PLANTS IN FINLAND

Sustainable Biogas project
D.2.1

JOHN NURMINEN FOUNDATION AND CENTRE FOR ECONOMIC DEVELOPMENT, TRANSPORT AND THE ENVIRONMENT FOR SOUTHWEST FINLAND

30.6.2021

European Union
European Regional Development Fund

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1. INTRODUCTION

1.1 Purpose of the report

This report is deliverable D.2.1 of project Sustainable Biogas, which aims at promoting the sustainability of biogas from a water protection perspective. The project is financed by the Interreg Central Baltic programme.

The purpose of this report is to review the current practices of biogas production and its regulation in Finland from the nutrient management perspective. The main pathways of nutrients to the environment from biogas industry are firstly end-usage of the nutrient-rich digestates produced at the biogas plants; and secondly, the biogas plants where especially raw material and digestate storage and reject water management can pose nutrient management risks.

The report includes an overall description of the Finnish biogas production and its specific characteristics in comparison with the other Baltic Sea region countries and a more detailed review of two pilot regions, Southwest Finland and Åland Islands. The biogas production processes are grouped and described according to their specific features from the nutrient management perspective. This is followed by an analysis of the regulatory framework for permitting, monitoring and utilisation of end products, again focusing on the issues having a direct or indirect impact on nutrient discharges from the biogas industry.

In the end, conclusions on the overall situation and main challenges and shortcomings of nutrient management in the Finnish biogas production are drawn and good practices in nutrient management identified.

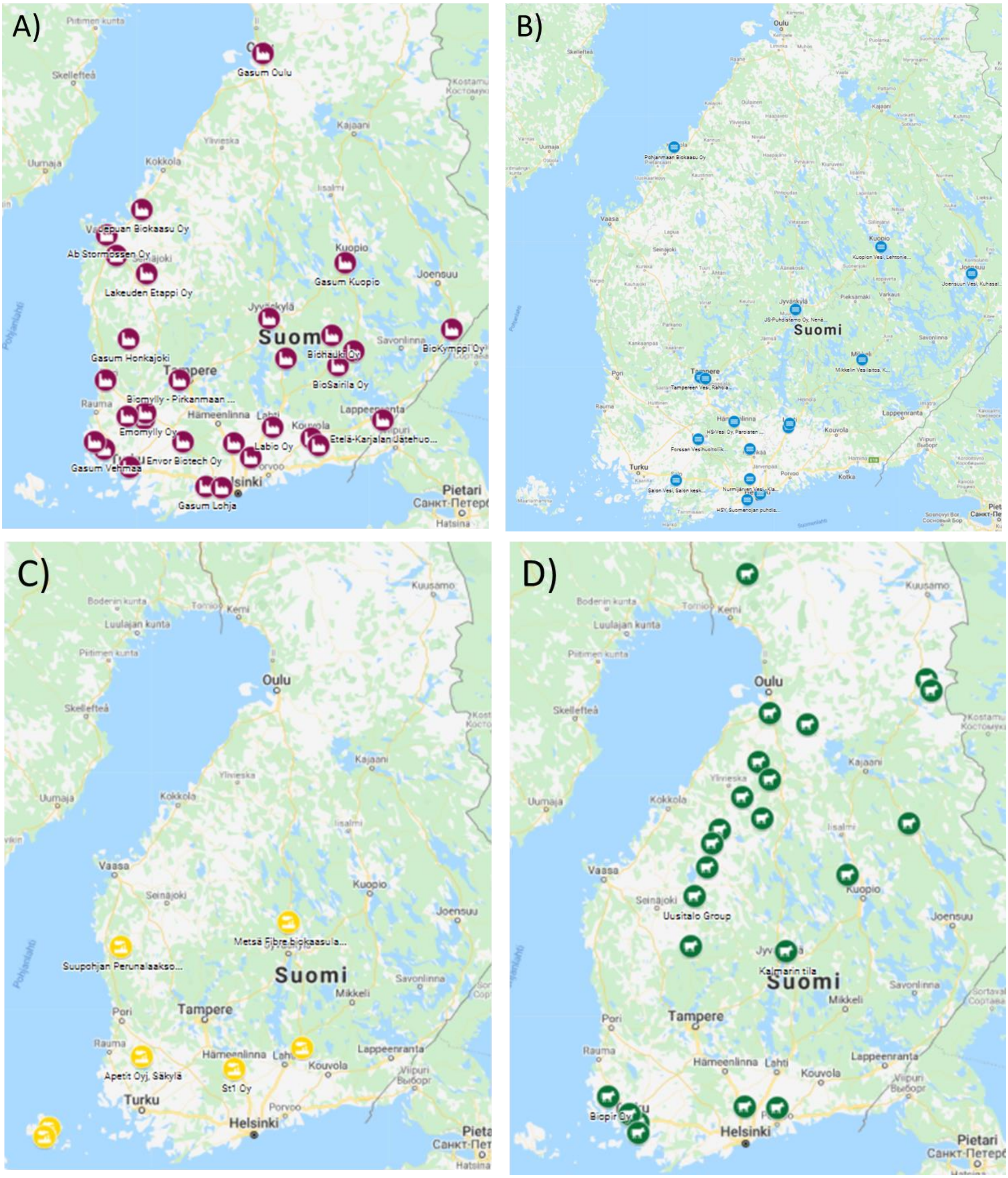
1.2 Biogas production in Finland

In 2017, biogas production in Finland amounted to 172 million m^3 (+10 % compared to 2016). Altogether 520 GWh of heat, 178 GWh of electricity and 30 GWh of vehicle fuel were produced from biogas, corresponding to about 0,5 % of renewable energy production in Finland. Production in reactor plants totalled 496 GWh and in landfill gas recovery plants 203 GWh (Huttunen et al. 2018). Due to the nutrient management point of view, however, the landfill gas will be excluded from the scope of this study.

Biogas production in Finland mostly takes place in large, centralised units. Co-digestion plants accounted for 62 % and large wastewater treatment plant (WWTP) biogas plants for 34 % of biogas production in reactor installations in 2017. These centralised plants are mainly located in the vicinity of cities and thus the sources of waste and wastewater sludge. Industrial and farm-scale biogas plants accounted for only 4 % of biogas production in reactor installations in 2017 (Table 1). More recent information dating from 2021 is available on the number and location of biogas plants (Figure 1 and Table 1).

Most of the large biogas facilities in Finland operate continuously fed mesophilic wet reactors, while some large plants and farm-scale plants with the dry process also exist (Table 1).

Figure 1. Location of A) Co-digestion plants, B) WWTP biogas plants, C) Industrial biogas plants and D) Farm-scale biogas plants in Finland (2021). Source: Suomen Biokaasulaitokset 2021



SUSTAINABLE BIOGAS

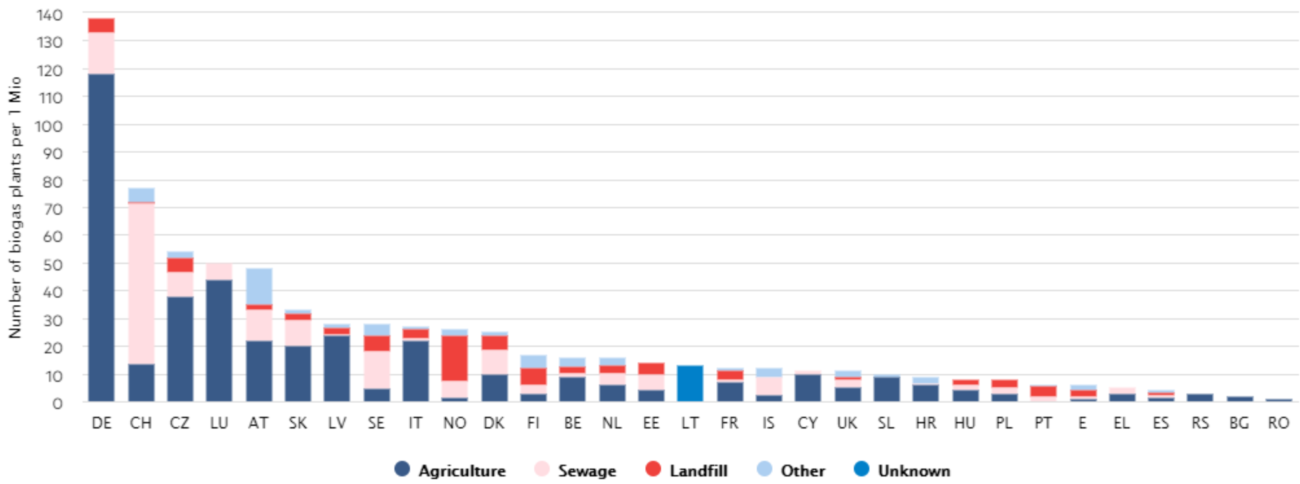
Table 1. Biogas production (2017) and number of plants (2017 and 2021) by plant type. Sources: Huttunen et al. 2018 and Suomen Biokaasulaitokset 2021

Type of installation	Feedstock	Biogas production process	Biogas production (Mm^3 in 2017)	Number of plants (2017)	Number of plants (2021)
Co-digestion plants	Biowaste, sewage sludge, side streams of food industry, and/or agricultural side streams	Wet, dry, Bionolix	61,429	24	30
WWTP biogas plants	Sewage sludge	Wet	33,652	16	16
Industrial biogas plants	Industrial side streams and waste products	Wet, IC, IR	3,350	4	7
Agricultural biogas plants	Manure, agricultural side streams, energy crops	Wet, dry	1,440	15	23
Total			**99,871**	**59**	**76**

In comparison to many other European biogas producer countries, the Finnish biogas industry is characterised by a low share of biogas plants with agricultural feedstock and a dominance of landfill gas recovery plants and biogas plants treating sewage sludge and mixed feedstock (Figure 2).

The greatest potential for the future lies in agricultural biomasses, such as manure and grassland, but policy instruments associated to them are not yet in place. Tightening recycling obligations are also likely to increase the amount of biowaste available.

Figure 2. Number of biogas plants (total and by feedstock type) per 1 million capita in Europe in 2018, arranged by descending order. Source: Nordic Council of Ministers 2020 (based on data from European Biogas Association)



2. NUTRIENT MANAGEMENT IN BIOGAS PRODUCTION

2.1 General

Organic biomasses used as feedstocks in biogas production contain considerable amounts of nutrients, namely nitrogen, phosphorus and potassium, and these nutrients remain in almost similar amounts in the digestate. Digestates are used as fertilisers in agriculture or in landscaping. The regulation related to the use of digestates is discussed in chapter 3.

According to the estimates by the Natural Resources Institute Finland, annual phosphorus consumption (including agriculture, forestry, landscaping, and fish farming) in Finland totals 33 800 tonnes and annual nitrogen consumption 234 600 tonnes. Of these amounts recycled fertilisers, including also digestates, correspond to 8,2 % of phosphorus and 2,4 % of nitrogen. (Marttinen et al. 2017)

Biogas production enables the co-processing of various nutrient rich organic biomasses into a form that can be further processed into recycled nutrient preparations. The digestion residues are often more homogeneous, fast acting and more hygienic when used as a fertiliser than if the input materials were used as a fertiliser as such. Hygienisation through digestion or composting allows the utilization of sewage sludge. Digestion based recycled fertilisers can also be used to add organic matter to arable land, which, in addition to the fertilizing effect, has several other positive effects compared to mineral fertilisers. Organic matter stimulates the soil's microorganisms, improves the soil's water economy and carbon sequestration, and reduces erosion.

The processing of biomass through a biogas plant can facilitate export of excess nutrients to nutrient deficient areas. This often requires digestate to be further processed after being removed from the digester. Techniques for nutrient recovery from digestate are developing rapidly and aim to improve nutrient management especially in agriculture and in waste treatment systems. Digestate processing can be partial, primarily for the purpose of volume reduction, or it can be complete, refining digestate to pure water, a solid biofertiliser fraction and fertiliser concentrates. While partial processing uses relatively simple and cheap technologies, complete processing requires more sophisticated process equipment and often has a high specific energy consumption, which implies high additional costs.

In Finland, digestate from biogas plants is rarely further processed. Most often, the digestate is separated into a dry and wet fractions and transported for use. Only a few biogas plants further process digestate into concentrated products or are testing further processing. So far, the drivers of the further processing of the liquid fraction separated from the digestate have been high fees or restrictions on their treatment in a wastewater treatment plant, and the need to reduce the transportation and storage costs of the liquid fraction.

In terms of nutrient use, sustainable biogas production takes into account and manages nutrient losses throughout the whole production chain. Sustainable biogas production recognises the nutrient emission risks and minimises them in the production, storage, and transport of raw materials to the plants, in the plant operations themselves and also in the handling and use of nutrient-rich end products in agriculture, industry and landscaping.

2.2 Southwestern Finland

2.2.1 Inputs, plans for new biogas plants

In Finland, there are no exact country-wide statistics on the quantities of feeds suitable for biogas production. Some of the information is more accurate, while most of the amounts need to be estimated based on the best available information. The accuracy of background data will improve as the study area shrinks, and a few regional or local surveys of biomass suitable for biogas production have been carried out in the country, based on both regional and other smaller boundaries (e.g., surveys of the Archipelago Sea, the Bothnian Sea, and the River Karvianjoki).

This chapter explains biogas production in Southwestern Finland (the provinces of Satakunta and Southwest Finland). The data has been collected mainly from the environmental permits and permit control data of the facilities and information received from the Finnish Biocycle and Biogas Association (SBB). Small farm-sized biogas plants may not require an environmental permit, so data may not have been obtained for this review. The number of biogas plants is indicative only due to uncertainties in the background information.

According to information collected from different data sources in Southwestern Finland there are currently 19 operating or planned biogas plants (Figure 2). Five of these are operating landfill gas collection facilities, so there are 13 biogas plants in the area to be considered in this review (Table 2).

There are 8 co-digestion plants using both sewage sludge and other organic biomass as feeds, and one is currently under construction. There are 4 farm scale biogas plants, and three have been authorized to start operations. Only one biogas plant in the area deals only with industrial waste biomasses and one can be classified as a WWTP biogas plant that digests only sewage sludge. Biogas plants in Southwestern Finland are permitted for waste treatment, not for fuel or energy production.

The process method for biogas plants in Southwestern Finland is mainly wet digestion process. Only two plants use dry digestion as a method (Table 2).

The feedstocks include sewage sludge, by-products of the food industry, biowaste and agricultural grasses. Recently, the need to treat residues from the bioethanol and the biodiesel industries has also emerged. The digestates from these plants are used almost entirely to field fertilization. Digestates from plants which use almost exclusively sewage sludge as feed material are used for landscaping. Farm-scale plants use a wide variety of feeds, most often pig slurry and overage fodder. Digestate from farm-scale plants is most often used on the farm's own or nearby fields as fertilisers.

Biogas is currently of huge interest in Finland. Preparatory funding has been requested for plant design and investment funding for construction from various funding sources and environmental permits have been applied. At present, three farm-scale biogas plants in Southwestern Finland have received environmental permits and several bigger plants are in preparation.

Table 2. Permitted biogas plants in Southwestern Finland. Provinces: SW = Southwest Finland, SK = Satakunta) (Source: YLVA control system)

BIOGAS PLANTS IN SW FINLAND						
Production method	**Plant**	**Situation 2021**	**Province**	**Plant type**	**Capacity ton/a**	**Input quality in environmental permit**
Co-digestion plant	Gasum Oy Turku	In operation	SW	Wet	150000	Sewage sludge and other biodegradable wastes and side streams
WWTP biogas plants	Salon Vesi, liikelaitos	In operation	SW	Wet	36 500	Sewage sludge
Farm-scale plant	Qvidja Kraft AB / Kuitian Voima Oy	In operation	SW	Dry	1800	Manure, field biomass, fish processing and horticultural by-products, secondary fish from management fishery
Farm-scale plant	Ammattiopisto Livia	In operation	SW	Wet	3000	Pig slurry, grass, maize, broad bean, oat etc. small amounts agricultural residues
Farm-scale plant	Biopir Oy	In operation	SW	Wet	19 900	Pig slurry and field biomass
Farm-scale plant	Mty Lähteenmäki	In operation	SW	Wet	7780	On-farm manure fractions and on-farm contaminated or overage fodder
Industrial biogas plant	Apetit Oyj, Säkylä	In operation	SK	Wet	10500	Wastewater from the food industry
Co-digestion plant	Gasum Oy Vehmaa	In operation	VS	Wet	120000	Pig slurry, biowaste, and other industrial biodegradable fractions, sewage sludge
Co-digestion plant	Biolinja Oy Uusikaupunki	In operation	SW	Wet	18000	Biowaste (community and industry), edible fats, fish sludge
Co-digestion plant	Gasum Oy Huittinen	In operation	SK	Wet	60000	Sewage sludge, biowastes and by-products from the food and agriculture
Co-digestion plant	Emomylly Oy	In operation	SK	Wet	19000	Biowastes and by-products from the food and agriculture
Co-digestion plant	VSS Biopower Oy	In operation	SK	Dry	19000	Biowastes and by-products from the food and agriculture
Co-digestion plant	Gasum Oy Honkajoki	In operation	SK	Wet	60000	Sewage sludge, biowastes and by-products from industry
Co-digestion plant	*Envor Pori, Luotsinmäen biokaasulaitos*	*Under construction*	*SK*	Wet	*30 000*	*Sewage sludge and fats and by-products from food industry*
Farm-scale plant	*Ruohosen Tila Oy*	*Under construction*	*SW*	*Wet*	*8 600*	*Cattle manure (dry and slurry) and surplus grass / silage*
Farm-scale plant	*Tyykilä Oy*	*Not built, but planned*	*SW*	*Wet*	*9 300*	*Cattle and broiler manure, silage and vegetable residues*
Farm-scale plant	Rantelli Oy	Not built	SW	Wet	16 000	Manure, silage, and industrial by-products
Farm-scale plant	*Kanakumppanit Oy*	*Does not operate*	*SW*	*Wet*	*4 000*	*Chicken manure*

2.2.2 Identified challenges in nutrient management in Southwestern Finland

There is a lot of crop cultivation, poultry farming and animal husbandry in southwestern Finland. As farm sizes increase and animal and plant production diversify and concentrate in different areas, areas of nutrient surplus have been formed. The amount of phosphorus and nitrogen produced in different biomasses, including manure, agricultural residues, biowastes and wastewater sludge, of Southwestern Finland was calculated in Sustainable Biogas project. A total of approximately 5 658 tonnes of phosphorus is generated annually in southwestern Finland, of which 1 831,6 tonnes are generated in the Satakunta region and 3 826,4 tonnes in the region of Southwest Finland. Compared to the phosphorus demand of plants for the entire study area, approximately 2 539 tons of more phosphorus is generated than is needed for fertilising the fields. The P surplus is about 831 tonnes in the Satakunta region and 1 708 tonnes in the region of Southwest Finland (Vahanen Environment Oy 2021).

Biogas production does not reduce the amount of nutrients contained in the biomass formed in southwestern Finland, but processing can enable the transport of surplus nutrients to nutrient deficit areas both within and outside the region. However, biogas production may reduce the separation efficiency of manure phosphorus into the dry fraction as digestion reduces the solid fraction content of digested manure biomass in comparison with raw manure (Hjort et al. 2010). This can increase the transport cost of digested manure phosphorus compared to processed raw manure if the value of the energy produced is not taken into account.

Based on the environmental permit conditions of biogas plants in the region, the permitting authorities have paid attention to the nutrient management topics presented below.

Raw material storage

- Raw material storages must be large and tight enough to avoid overflows in case of process disturbances and e.g., nitrogen evaporation during storage.

Anaerobic fermentation process

- The structures and equipment must prevent leakages during emptying, transfer, and transport. The biogas plants must carry out all processes indoors, including the reception of feedstock, fermentation process, storage, possible separation and loading for further use.
- The process equipment of the biogas plant as well as the monitoring and alarm equipment related to the monitoring of operations must be kept fully functional. Equipment must be regularly maintained, and any equipment failures must be repaired without delay. A record must be kept of the maintenance measures carried out and of any disturbances. The records shall be made available to the environmental /monitoring authorities, as appropriate.
- Biogas plants that convey nitrogen-containing reject water to wastewater treatment plants burden the wastewater treatment process both quantitatively and especially qualitatively. The quantity and quality of reject water and its variations should be considered when planning the contract/practice. Ideally, the reject water should be utilised as nitrogen products to avoid conveying it to a wastewater treatment plant. This way the treatment plant will be able to use its capacity in accordance with its operating strategy to treat municipal wastewater.

Digestate storage

- To avoid evaporation of nitrogen, digestate should be stored in a closed storage tank until application takes place. The tank must be filled from below and covered with at least a floating cover. The pH value of fresh digestate is typically higher than the average pH for raw substrates. Increased pH indicates the degradation of offensively smelling VFAs, which reduces odour emissions, but increases ammonia volatilisation. Digestate should be as soon as possible incorporated in soil after application to prevent excess ammonia emissions.

- The plants should have adequate storage capacity of digestates. Particularly the farm-scale plants may face challenges if the digestate is not sent to field application as planned, for example due to weather conditions. The biogas plants should have storage facilities corresponding to 12 months' production of digestates and/or separated fractions and reject water.
- Rainwater and meltwater must be prevented from entering storage areas.

Digestate transport and application

- Solid–liquid separation is the most frequent first step in digestate processing. It improves the cost-effectiveness of transporting digestate. The separated solid P-rich fraction can be transport further and applied directly for agricultural purposes with the advantage of considerably lower transport costs due to the reduced water content. Another advantage is that the solid fraction can be stored under much simpler conditions. As an alternative to direct land application further stabilisation and transformation into a marketable product can be achieved, e.g. through drying or composting (IAEA 2015). Separation must be carried out in a covered space on a compact surface which has been designed in such a way that leaks into the environment cannot occur even in the event of a breakdown of the separation unit.
- Digestate should be as soon as possible incorporated in soil after application to prevent excess ammonia emissions. However, the superior infiltration speed of digestate into soil compared to raw manure/slurry lowers the risk of excess ammonia volatilisation if digestate is handled according to best agricultural practices.
- To prevent leakage during vehicle transport, transport must be carried out in covered tanks.
- Transport and distribution must be arranged in such a way as to minimise odours to the environment. In particular, in fields close to settlements, care must be taken to ensure that application and mulching do not cause odour nuisance.
- Sufficient arable land must be available for the application of digestate. In nutrient excess areas such as Southwest Finland, it might be challenging to find suitable areas for the field application of digestate. It must be noted, however, that if biogas digestate is processed into a fertiliser/soil amendment product, the processor needs an environmental permit to receive digestate, but the intended use of the product does not need to be known.

2.3 Åland Islands

This chapter presents the biogas facilities and challenges in nutrient management related to biogas production in Åland Islands. Main sources of information are interviews of biogas operators and local authorities, and environmental permits of the factory or wastewater treatment plant whose wastes are digested.

Åland Islands is also a nutrient surplus region. Statistics and information on biomasses are scattered and not very easily available in Åland.

2.3.1 Inputs, plans for new biogas plants

Currently there are 3 biogas plants operating in Åland Islands and one plant is planning to launch test operations (Table 3). All the currently operating facilities operate in conjunction with a factory or a wastewater treatment plant. Feedstocks used at the co-digestion plants are manure and industrial wastes, i.e., potato and dairy production residues. The biogas plant operating in connection with the wastewater treatment plant uses only sludge as feed.

The plants are relatively small with annual gas production capacities ranging from 430 000 to 1 400 000 m^3/a. Wet process is used in all the facilities. Biogas production is included into the environmental permits of the factories or plants as part of their operations.

The new plant is applying for an environmental permit and will start with test scale. Once in operation, it will deviate from the existing facilities, utilising dry process and using a wide range of household and industrial waste as feedstock. In addition, the production capacity can be increased with a modular solution. Also, the digestate is further processed in pyrolysis to produce biochar which can be used as a fertiliser, as a nutrient additive in animal feed and as a filter material and a carbon sink.

The Government of Åland (Ålands Landskapsregering) is preparing a biogas strategy for Åland to increase knowledge and to create a framework for the future of biogas production in Åland Islands. The experiences from the future plant of Svinryggen Deponi is believed to bring new information to this work.

Table 3. Biogas plants in Åland Islands

BIOGAS PLANTS IN ÅLAND ISLANDS					
Production method	**Plant**	**Situation 2021**	**Plant type**	**Capacity m^3/a**	**Input quality**
Co-digestion plant	Orkla Confectionery & Snacks Oy, Haraldsbyfabriken	In operation	Wet	1 400 000	Potato residue, manure
Co-digestion plant	Ålands Centralandelslag, ÅCA	In operation	Wet	670 000*	Residues from dairy production
WWTP biogas plant	Lotsbroverket in Mariehamn	In operation	Wet	Not limited in permit (425 600 in 2020)	Sewage sludge
Co-digestion plant	Svinryggens Deponi	Planned	Dry	Up to 300 000	Household and restaurant biowaste, garden waste, slaughter waste, vegetable waste, dead fish from fish farming, wood waste

*data from the Finnish Biocycle and Biogas Association

2.3.2 Identified challenges in nutrient management in Åland Islands

Challenges mentioned below are based on interviews with biogas operators and authorities. In general, there were not many challenges associated with biogas production.

Raw material storage

At present most of the feedstocks come directly from the previous process to the biogas plants, thus there are not many storages at the biogas plants in Åland. In case the use of different feedstocks increases it is important to pay attention to the storage facilities i.e. covers on top of the storages to prevent leakage and nutrient losses. In addition, the need for monitoring must be evaluated.

Anaerobic fermentation process

Reject water from the sewage sludge-based plant cannot be used as irrigation water because of the bacteria it contains. Instead, the nitrogen-rich reject water is directed back to the purification process, which causes a large internal load on the entire plant. About 10% of the nitrogen treated at Lotsbroverket comes from the reject water, restricting the amount that can be received from outside. As a result, the biological process that purifies nitrogen is heavily burdened.

To alleviate the pressure at the wastewater treatment plant, reject water and wastewater from the other biogas plants are pre-treated at the biogas plants before they are directed to Lotsbroverket for purification.

Digestate storage

Only mobile storages for digestates are used in Åland. There are containers or tanks where the digestate is stored until it is collected by the end user or the processor. Still, it is important to pay attention to drainage of the storing areas.

Digestate transport and application

Spreading of digestate is quite tightly regulated in food production but less supervised when it comes to gardens, forests, or roadsides.

The use of wastewater sludge and sludge-based digestate is challenging. Currently sludge-based digestate is mixed with wood chips, ashes, residue from fish farming and sand and then it is composted for at least 6 months and up to 1 year. The final product is a substrate for lawn which is sold both to private individuals and to landscaping. Demand is low since it contains plastic residues, small amounts of heavy metals, and possibly also drug residues and other harmful substances.

3. REGULATION AND PRACTICES

This chapter discusses the most relevant regulations and administrative practices affecting nutrient management at biogas plants.

3.1 Permitting and contracts

Environmental Impact Assessment (EIA)

In mainland Finland, an environmental impact assessment (EIA) process is required for large new biogas plants processing more than 35 000 tons waste feedstocks per year (EIA Act 252/2017 and Decree 277/2017), and for capacity expansions in old plants, if the increase in the processing capacity exceeds 35 000 t per year. In the EIA, the impact of the plant is evaluated, and alternative options are studied. The process is monitored by the Centres of Economic Development, Transport and the Environment (ELY Centre).

According to ELY Centres, the 35 000 t threshold can refer to other feedstocks than waste, too, if the share of wastes of the total feedstocks is very high. In addition, an EIA can be required for smaller plants if the environmental impacts are considered considerable as such or taking into account the existing activities in the area (e.g. in case two plants are polluting the same area/watercourse and their combined effect is significant).

During the EIA process, the stakeholders affected by the activity are widely consulted. As a result of the process, an EIA report is prepared, and the liaison authority issues a reasoned conclusion. The information obtained from the EIA documents is used in the permit process. A reasoned conclusion must be reached before an installation can be granted an environmental permit, a Tukes permit or a commissioning permit under Land Use and Construction Act (132/199).

In Åland Islands, an EIA process is not required for biogas facilities, but the operator can perform an EIA by himself on a voluntary basis or request for an assessment or review from Environmental and Health Protection Agency of the Åland Islands (ÅMHM). The main regulations outlining the EIA process and permitting of biogas plants are the so-called MKB Act (2006:82) and the Environmental Protection Act (2008:124) and Decree (2008:130) of the Government of Åland.

Best available technique (BAT)

Biogas plants must operate in accordance with the best available technology for waste management WT BAT (waste treatment best available technique). WT BAT prescribes for air and water emissions management and monitoring. If the plant has direct or indirect discharges into the water body, regulations must be issued in the environmental permit for the monitoring of discharges where the water body is interpreted more broadly than the Water Act, i.e. emissions to the ditch are also taken into account. Best available techniques must also be used to control odour nuisances, and smaller plants must use the WT BAT even if they are not BREF controlled. The BREFs are a series of reference documents covering, as far as is practicable, the industrial activities listed in Annex 1 to the EU's IPPC Directive. They provide descriptions of a range of industrial processes and for example, their respective operating conditions and emission rates. Member States are required to take these documents into account when determining best available techniques generally or in specific cases under the Directive.

Environmental permit

For many biogas plants, the obligation to hold a permit derives from professional waste handling including manures, solid waste and sludges, or from fuel production exceeding 5000 t/a (Environmental Protection Act 527/2014). Another reason is nuisances to neighbouring properties (Adjoining Properties Act 26/1920).

A biogas plant needs to apply for an environmental permit before starting operations in mainland Finland. The permit is granted by a municipal environmental authority or a Regional State Administrative Agency (AVI), depending on how much waste the facility handles per year. AVIs permits the facility if it receives more than 20 000 tons of waste per year. Municipality's environmental authority is the permitting authority for smaller installations (Environmental Protection Act 527/2014 and Decree 713/2014). The municipality supervises the facilities it has licensed. Biogas plants licensed by AVI are supervised by regional ELY centres.

Biogas plants at large-scale animal shelters that require an environmental permit have usually been integrated in the environmental permit of the farm and permitted by AVI, but the animal farm and the associated biogas plant may also be permitted separately. The supervisory authority carries out an assessment of the need for a permit and may state in its assessment that there is no need to amend the authorization.

From the nutrient management point of view, the most important parts of the permit application are chapters on pollution and waste, on environmental impacts, on risk prevention measures and on an environmental impact monitoring plan. Furthermore, plants treating waste need to submit a document on what kind of waste is collected and from where, how it is transported, utilised and how the process works in general.

A key part of the permit are the permit regulations, and the supervision of the plant focuses specifically on the implementation of these permit regulations. To avoid environmental problems related to overloading, the permit decision also specifies the maximum capacity of the plant, i.e. the maximum amount of waste that the plant may receive and/or treat.

Permit regulations are issued to avoid damage to the plant's immediate environment. Commonly, they address odour nuisances and water discharges, as well as the further treatment of digestate and stormwater. The aim is to minimise damages to watercourses by issuing permit regulations concerning stormwater or other wastewater (e.g. condensation water) generated on the site if the treated wastewater is discharged e.g. into a ditch. Concentration and load limit values can be assigned to certain parameters for wastewater and their monitoring can be ordered. Monitoring of waterbodies can also be ordered.

In Åland, an environmental permit is needed for waste management, but not if an operator treats waste generated within its own operations. However, a permit is required for anaerobic biodegradation exceeding 100 tonnes per day. A permit is also required if more than 100 tonnes of digestate is produced per day. None of the current biogas plants has a separate environmental permit for biogas production, but extra conditions for biogas production have been added to their permits that are related to other operations of the companies.

The permitting authority is ÅMHM. Usually, a permit is granted until further notice, but requirements are revised and possibly updated every ten years or whenever ÅMHM deems it necessary. Also, the operator or a stakeholder has the possibility to request a revision of the permit. In general, since the number of biogas plants in Åland is so small there are no general lists or guidelines how to proceed with permitting of biogas facilities and formulate the requirements, instead each plant is assessed on a case-by-case basis. Typically, terms and conditions related to nutrient management set in the permit are for: wastewater directed to wastewater treatment plant, sufficient digestate quality and digestate treatment, storage, requirements for the recipient of the digestate, and requirements for digestate transport. In addition, plants must keep logbook on their operations and submit an annual report to ÅMHM.

Industrial wastewater contract

The load to WWTPs from industrial sources, such as biogas plants, is usually regulated with industrial wastewater contracts between the WWTP owner and the company discharging industrial wastewater to the WWTP. In these contracts, the wastewater fee is typically defined based on wastewater flow and quality indicators. Flow and quality limits and sanctions for violating them are also defined.

Waste and animal feedstocks and authorisation for the fertiliser use of digestate

Several regulations and standards are applicable for raw materials, depending on the nature of materials treated at the biogas plant. E.g. the animal by-products regulation (No 1069/2009) is general within the EU and states the terms for prevention of spread of diseases within the processes of moving materials of animal origin. In addition, waste legislation defines the handling of products classified as waste.

If the biogas plant receives animal by-products or waste, the product must be hygienised, post-composted and cooled before use and must not cause odour nuisances.

The Finnish Food Authority grants authorisation for biogas plants producing organic fertilisers or their ingredients for external use. Furthermore, fertiliser products placed on the market in Finland must be included either in the national type designation list of fertiliser products or, in the case of EC fertilisers, in the list of EC fertiliser type designations specified in Annex I to EC Regulation 2003/2003 (Fertiliser Product Act 539/2006 and Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011).

In Åland the applied regulation is Fertiliser Product Act (539/2006) and Åland Regional Act (2007: 96) on the application of the Fertiliser Products Act which broadly corresponds to the Finnish Fertiliser Product Act. A biogas plant producing organic fertiliser must first be approved by the Agricultural Bureau or the Environmental Bureau at the Åland Government. Furthermore, organic fertiliser products and their product declarations are approved by the Agricultural Bureau and the producer also reports to the Bureau and complies with the agreed self-monitoring plan. The use of animal by-products is approved by the Government veterinarian at the Environmental Bureau.

A trade announcement is also required by the Finnish Food Authority if the biogas plant processes animal products, municipal or industrial wastewaters or similar external waste products or if the biogas process residue is sold as fertiliser products. In practice, almost all biogas plants apply in this process, except for farm biogas plants that only process their own waste and use the residue within their own farm as fertilisers.

3.2 Monitoring

Biogas plants and their environmental permits are supervised by ELY Centres (large plants) or by municipal environmental authorities (small plants). In most cases, plant operations are monitored through self-monitoring and periodic inspections by the supervising authorities. The self-monitoring is based on the monitoring plan approved by authorities. A summary report of the monitoring results must be prepared annually and approved by the monitoring authority. The monitoring involves e.g. the following:

- Amount and source of the raw materials used
- Quality, amount, and delivery location of end products
- Stored materials at the end of the year
- Quality and amount of wastewater produced
- Summary of environmental monitoring at the plant and an assessment of the environmental impacts of the plant

Control under the environmental permit is risk-based. ELY Centres use a two-stage risk assessment method, in which the probability and effects of environmental risks are assessed both by industry and by plant type.

The risk criteria takes into account the size and location of the plant and the results of impact monitoring, complaints, violations, etc. Based on the risk assessment, periodic inspections are performed.

In Åland Islands the supervising authority for environmental permits is ÅMHM. Currently biogas plants are not monitored separately but as a part of the operations of the company. The reports are submitted annually to ÅMHM. Self-monitoring can include for example:

- Raw material volumes
- Biogas production volume
- Volume, quality, and recipient of digestate and wastewater
- Storage capacity
- Documentation on the hygienisation process
- Faults and malfunctions that could have effects on environment

In addition, the quality of fertiliser products is monitored by the Finnish Food Authority and there are also monitoring requirements for the use of digestates in agriculture (see chapter 3.3 Utilisation of end products).

3.3 Utilisation of end products

Agriculture

In the Southwest of Finland, decrees implementing the Nitrates Directive (1250/2014, 435/2015) set limits for nitrogen and the Decree on Fertiliser Products (24/11) and its amendments (e.g. 5/2016) for soluble phosphorus and cadmium. In addition, fertiliser application is limited by the rules for environmental compensation for farms receiving this subsidy.

In Åland Islands, the use of digestate is regulated by Decision 2016:41 and Decree 2016:42 implementing the Nitrates Directive and for phosphorus the Decree on Fertiliser Products (24/11). As majority of farms participate in EU's environmental compensation scheme for agriculture it restricts the use of digestates too.

In summary, the limits for nutrient application in agriculture are the following:

- Maximum amount of **soluble nitrogen** is 30 - 250 kg/ha/a depending on crop and soil fertility.
- The amount of **total nitrogen** from manure and fertiliser products containing manure is limited to 170 kg/ha. The total nitrogen limit does not apply to other organic fertilisers, however, and the total amount of total nitrogen may be higher than 170 kg/ha, as, in addition to manure-based fertilisers, other organic and inorganic fertilisers may be applied until the limit for soluble nitrogen is met.
- Maximum application of **soluble phosphorus** are 325 and 560 kg/ha in 5 years in agriculture and horticulture, respectively.
- Maximum amount of cadmium is 1.5 g/ha/a or 7,5 g/ha in 5 years, which may limit the amount of cadmium-rich fertiliser products and indirectly the amount of applied nutrients. However, in such cases, the maximum amount of nutrients will typically be applied by using a mineral fertiliser.

According to the rules for environmental compensation,

- The maximum amount of **soluble nitrogen** is 20 - 240 kg/ha/a depending on the crop and soil fertility.
- The maximum amount of **total phosphorus** is 0 - 63 kg/ha/a depending on the crop and soil fertility. However, this is a calculated value and may differ from the actual total phosphorus input[1].
- For grains and oil plants, additional amounts of **soluble nitrogen** (10- 50 kg/ha) or **total phosphorus** (3 – 6 kg/ha) may be applied if the crop production meets the requirements for high crop yield.

Apart from nutrient application volumes, the regulations also restrict the fertiliser application methods, timing, distance to water bodies, etc. In addition, there are specific limitations for the agricultural use of sewage sludge-based products with sewage sludge content of more than 10 %. They can be applied to grains, sugar beet, oil plants and other plants not aimed for human or animal consumption. Root vegetables or grass cannot be grown within 5 years after using such a product. In addition, the maximum allowed heavy metal limits in soil and maximum load of heavy metals are defined.

In 2020, most of the arable land in southwestern Finland was covered by EU's agricultural subsidies and specifically its environmental compensation system which limits the amount of applied phosphorus. However, it needs to be noted that although the environmental compensation system sets limits to phosphorus application, it allows for fertilisation rates which are higher than plant needs. The participation rate of farms in the environmental compensation scheme in the financing period 2014-2020 was 87 % in the whole Finland (Kauppila et al. 2017). Fertilisation of the fields of farms receiving EU environmental compensation is systematically monitored by ELY centers in accordance with the EU

[1] 100 % of total phosphorus in the products is taken into account for manure, 60 % for sewage sludge and 40 % for ash.

environmental compensation control plans prepared by the Finnish Food Authority. It can be stated that in most of the cultivated areas the control of fertilization and thus the management of the risk of over-fertilisation is at a reasonable level.

Spot checks at farms receiving the agricultural subsidies are carried out by ELY and the Agricultural Bureau in mainland Finland and Åland Islands as instructed by the Finnish Food Authority. Nutrient management is checked against parcel accounting of the farmer.

Municipal environmental authority and ÅMHM are the monitoring authorities of the Nitrate Decree in mainland Finland and Åland Islands.

Landscaping

The products used for landscaping are typically required to meet the requirements of Fertiliser Product Act (539/2006), and the list of fertiliser product categories. Earlier, the application of soluble nitrogen and phosphorus was restricted to 1250 kg/ha and 750 kg/ha in 5 years, respectively. However, the existing Fertiliser Product Decree (24/11) and its amendments do not define such limits for landscaping.

In landscaping, the thickness of the fertile layer varies from 5 to 100 cm depending on the requirements of the vegetation. The recommended nutrient contents in landscaping materials for lawns and demanding plants is 15–100 mg/l (15–100 g/m^3) for **soluble nitrogen** and 5–30 mg/l (5–30 g/m^3) for **total phosphorus** (Viherympäristöliitto).

The amount and quality of fertiliser products used in large-scale landscaping, such as landfills and mines, is regulated in an environmental permit. A typical fertile layer is 10 - 30 cm, which corresponds to 1,000 – 3,000 m^3/ha of fertiliser product/soil improver.

Storage and landfilling

According to the Waste Taxation Act (1126/2010), waste can be stored for a maximum of 3 years prior to end use. Otherwise, the storage will be regarded as a landfill without a permit and the waste will be subject to waste taxation. Furthermore, according to the Landfill Decree (VNA 331/2013), digestate cannot be landfilled as its organic matter content is well above the highest allowed (10 %) for landfilled waste. The storage capacity of the biogas plants depends on the environmental permit. Typically, the facilities with a composting plant are required to be able to store the digestate produced within one year of operation.

4. CONCLUSIONS

4.1 Overall factors causing nutrient leakage risks

Increased nutrient solubility

Biogas production amends the chemical composition of both nitrogen and phosphorus of the raw materials used into a more soluble form. This is good for the plant availability of nutrients, which increases effective nutrient uptake and may reduce run-off, but in the case of over-fertilisation, can increase the leakage risk of soluble nutrients if the amount of nutrients available for the plants is greater than their need during the growing season. Soluble nutrients are more harmful for watercourses.

Lack of demand

The main nutrient management risks related with spreading of digestates arise from the lack of demand for digestate-based organic fertilisers due to their price competitiveness compared to mineral fertilisers. Mineral fertilisers are often cheaper than digestate-based products due to the transportation and processing costs of organic fertilisers. In addition, the usage of organic fertilisers often requires additional work in comparison with mineral fertilisers, for example different machinery or addition of nitrogen fertilisers. Moreover, the refusal of some Finnish food industry companies to use raw materials cultivated with sewage-based fertilisers has decreased the willingness of farmers to receive fertiliser products made of sewage sludge.

Lack of demand leads to nutrient management risks, as it is often costly and time-consuming to find end-users for digestates, especially in the nutrient surplus areas. The biogas producers mostly do not get compensation for their digestate-based fertilisers but must pay for the processing and give their end-products for free, often also covering the transportation costs.

The situation leads into an incentive structure favouring overfertilization. Processing may not help, if it further increases the price difference of digestate based fertilisers with mineral fertilisers.

For sewage-based digestates, the difficulties to find end-users for digestates have in some cases led to situations where the biogas plant storages have become overfilled and digestates have been leaking into the watercourses (Rolamo et al. 2018).

Legislative limits, permitting and monitoring

Especially for phosphorus in agricultural usage, the main steering mechanism limiting the applied amounts is the agricultural subsidy system. The current legislation allows for phosphorus application rates which are clearly higher than plant needs. If a farm using manure from its own biogas plant does not participate in the EU environmental compensation system, there are no legislative limits for phosphorus usage as the Fertiliser Product Degree does not apply to manure which has not been processed into products. In fact, over fertilisation with phosphorus can be a problem on all farms not receiving environmental compensation. Even for those types of biomasses which belong under the Fertiliser Product Degree, the monitoring of the 5-year phosphorus limit by the Finnish Food Authority is not systematic and regular.

In landscaping, in addition to the nitrogen limits set in the Nitrate Degree, there are no legally binding limits for nutrient application, only non-binding recommendations. This increases the risks of overfertilization within landscaping.

A functioning and clear legislative framework is currently missing for using recycled nutrients in agriculture and landscaping. The situation creates hindrances for investments and further processing of biomasses as recycled nutrients.

When issuing permits, environmental authorities can require a sufficient field area for sustainable usage of the produced organic nutrients but cannot monitor the actual usage of end-products or issue sanctions for exceeding the limits. Divided control and monitoring responsibilities between environmental and agricultural authorities cause challenges in nutrient management. Environmental authorities cannot monitor the usage of biomasses defined as products according to the End of Waste criteria, but as the demand for digestates is limited, there is a risk of overfertilization.

Awareness on nutrient management of biogas production

The fact that biogas plants produce two end-products, energy and nutrients, has often been forgotten especially in political decision-making. With the increasing pressure to find fossil-free energy sources, planning of the nutrient management side has been left out, also when planning steering mechanisms such as economic support systems. Even with the nutrient recycling compensation system, currently under consideration in Finland, the focus is mainly on supporting the collection of nutrient-rich biomasses. The financial and demand challenges of utilising digestates are often overlooked, although they are a major hindrance for their sustainable utilisation.

Nutrient management of biogas production has not always been thoroughly considered in environmental impact assessments, environmental permitting, and industrial wastewater contracts. For example, in history the additional nitrogen load in the form of reject waters has not always been accounted for when discharging wastewaters to municipal wastewater treatment plants.

Location of biogas plants in nutrient surplus regions

Biogas production has concentrated in regions which already have nutrient surplus due to animal production. This is logical as production is in the same regions where the raw materials such as manure are formed, and it does not affect the existing nutrient surplus as long as the raw materials come from inside the same region.

However, as biogas plants are costly investments and their economic viability increases with the increasing plant size, the plants often utilise raw materials from outside the region where they are located. This increases the amount of nutrients in the region. For example, sewage sludge from the cities in south-eastern coast of Finland, such as Porvoo and Hamina, has been transported to the Topinoja plant, located in the nutrient surplus region of south-western Finland. However, it needs to be noted that while the south-western Finland region has a nutrient surplus as a region, there may still be some nutrient deficient municipalities inside the region.

In some cases, the economy of scale has led biogas plants to increase their production faster than sustainable nutrient management allows. When taking in new nutrient containing raw materials, the plants have not had receivers for the increasing amount of digestates.

4.2 Identified nutrient risks and first ideas for solutions

Based on the analysis of environmental permits and regulation, the main nutrient leakage risks from the biogas production chain are related to the use of digestates. Some recent experiences also suggest that attention needs to be paid to the treatment of reject waters and to the storage arrangements of feedstocks and digestate / end products.

For good practices and/or associated first ideas on how to tackle the risks, see the text below *in Italics*.

4.2.1 Over-fertilisation

In the current EIA and permitting processes, the regional nutrient balance i.e., whether a biogas plant is planned in an area of nutrient deficiency or nutrient surplus cannot be considered. Biogas plants in a nutrient surplus area may also plan to receive feedstocks from nutrient deficient areas, thus further distorting the nutrient imbalance. Only in case of animal shelters, the permit authority controls that there is enough field area for spreading the manure / digestate and that manure is not spread on field parcels with high P levels. In other cases, the permit authority cannot control the use of digestates.

The nutrient management risk related to the concentration of the digestates in nutrient surplus areas arises from the fact that it is often too costly to transport the nutrients into nutrient deficient areas. Consequently, digestates may accumulate in storages or be used in agriculture or landscaping in excess of plant needs:

- In agriculture, the current legislation allows application rates that higher than plant needs. In 2014, Ylivainio et al. estimated that 73 % of fields in Southwest Finland and 76 % of fields in Åland were nonresponsive for P fertilisation due to high P levels in soils.
- Control over the use of fertilisers is minimal and irregular for the farms not receiving environmental compensation. However, the proportion of these farms is small thus the likelihood of large-scale overfertilization is low.
- Fertilization on farms not receiving funding from the EU environmental compensation system is less controlled. Phosphorus restrictions have been one of the main reasons why especially large poultry and pig farms having too much manure nutrients have left the environmental compensation system (Kauppila et al. 2017). The overfertilization problem may thus be

concentrated especially on these farms. Fertilization of arable land outside the environmental compensation system must comply with at least the maximum fertilization rates of the Nitrate and Fertiliser Products Decrees. The control of fertilization in accordance with the Nitrate Decree in areas outside the EU environmental compensation system is the responsibility of the municipal environmental protection authorities. Based on the information received, the municipalities do not have systematic monitoring of the use of fertilisers on the farms, but the use of fertilisers on the farm may be reviewed occasionally, e.g. in connection with various permit applications or on the basis of notifications from neighbours (which have been very few). The Finnish Food Authority is responsible for implementing the minimum requirements of the Fertiliser Product Decree. According to the information received, the control of phosphorus fertilization of arable land not receiving funding from the EU environmental compensation system under the Fertiliser Product Decree is marginal and there are no established control practices.

- Lack of legally binding restrictions for fertilisation in landscaping may lead to a potential risk for excessive use of soil amendment products, and eventually, to nutrient run-off especially now that landfilling of digestates is no longer allowed and sewage sludge –based digestate is not favoured by farmers.

This calls for awareness of the need for nutrient management in biogas production and emphasises the need to pay attention to regional nutrient balances in decision-making i.e., when planning locations and issuing permits for biogas installations. Overcoming the risk for nutrient leaching would require that the use of digestate / soil amendment products in both agriculture and landscaping are based on plant needs.

4.2.2 Reject waters conveyed to a municipal WWTP

In some cases, there has been insufficient information on reject water generated by a biogas plant, and the nitrogen load has led to problems at the receiving wastewater treatment plant. *Attention should be paid to reject waters in EIA, permitting and industrial wastewater contracts, and the local water utility and WWTP should be heard in the permitting process to avoid capacity problems.*

4.2.3 Storages

Appropriate storage of feedstocks and digestates / end products prevents nutrient leakages:

- *Storages for dry feedstocks are to have tight, durable substructures and sewer arrangements through which the accumulating liquids can be led to the tank for liquid feedstocks.*
- *Liquid, rapidly decomposing feedstocks should be stored in sealed containers.*
- *The loading and unloading areas are to be watertight and drained.*

*Water from loading, outdoor storage areas and vehicle washing areas shall generally be collected and if possible pumped into the biogas reactor after necessary pre-treatment (e.g. removal of sand, possible preheating). If not possible, the water shall be otherwise treated appropriately. (*Latvala 2009, Nordic Council of Ministers' 2020).

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Climate-friendly biogas may lead to nutrients entering the watercourses if the treatment of digestates and wastewater from biogas plants is not carefully planned.

The goal of the Sustainable Biogas project, funded by the EU’s Interreg Central Baltic programme, is to promote the sustainability of biogas from a water protection perspective.

The project is implemented by the John Nurminen Foundation, the ELY Centre for Southwest Finland, the Finnish Biocycle and Biogas Association, Latvian State Environmental Services, and the Latvian Biogas Association.