Tampereen ammattikorkeakoulu

Dry Digestion of Source-Separated Biowaste – Quality Requirements for Digestates in Agricultural Use, Case Nokia

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ABSTRACT

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Tampere Regional Solid Waste Management Ltd opens a new biowaste treatment plant in autumn 2020. After 20 years of aerobic composting, the treatment technology changes to anaerobic digestion. The technology can offer new competitive advantage, when waste can be turned into marketable products.

The purpose of this study was to help the new plant to produce not just biogas for transportation use, but also digestates for fertilisation purposes. This study concentrates on utilisation of the digestates from the dry digestion line of source-separated biowaste and garden waste. The aim was to find the requirements and expectations towards these recycled fertilisers.

The relevant European and national regulations concerning waste, fertiliser products and some agricultural practices were studied. Guaranteeing good quality digestate suitable for agricultural use, the feedstock of the process is of essential importance. In this study, the known feedstock values and estimated digestate quality were compared with the data found in literature. The challenges and the possibilities in the markets were identified through results of earlier interviews with producers and users of products in Finland and in Europe.

It became apparent that there are many regulations one needs to comply with, both from waste and agriculture section, and both from the producer's and the end user's point of view. The legislation has recently been renewed, and the changes need active follow-up. The quality of the digestate can be estimated, but the variations can be big. The solid digestate after composting proved to be a good soil improver, and the liquid digestate a decent fertiliser. There is a demand for these fertiliser products in Tampere region, but the market value is measured by solving the quality, storage and price issues.

To comply with the requirements of legislation and the customers, special attention should be paid to the quality of the digestates. Requirements in storage and application of digestates together with the need of knowledge of farming practices and marketing fertiliser products suggest incorporating a third party to share part of the work. At least in the beginning of operation, that would give time to learn to run the plant and produce biogas and good quality digestate, especially in the liquid form. Using a quality assurance system could help in marketing the fertiliser products, and that way, also the profitability of the plant.

Key words: biowaste, dry digestion, digestate, organic fertiliser product, quality

CONTENTS

ABBREVIATIONS AND TERMINOLOGY

AD	anaerobic digestion, micro-organisms decompose organic matter in airtight tanks to produce biogas
bioeconomy	economy that uses renewable biological resources to produce food, goods and energy
digestate	end product of anaerobic digestion process
DM	dry matter or dry weight as a measurement of the mass of something when completely dried
dry digestion	anaerobic digestion process, where dry matter content of the feedstock is between 20-40 %
feedstock	raw material or input material supplied to a process
fertiliser product	substances and products intended for promoting plant growth or improving the quality of the crop, where their impact is based on plant nutrients or other beneficial substances
FM	fresh matter or fresh weight as a measurement of the mass of something fresh
MMM	maa- ja metsätalousministeriö, the Ministry of Agriculture and Forestry
OFMSW	organic fraction of municipal solid waste
own-check system	system of a food business operator to help managing risks; ensuring premises, activities and products meet the requirement laid down in foodstuff regulations
PJH	Pirkanmaan Jätehuolto Oy, Tampere Regional Solid Waste Management Ltd.
soil conditioner/ soil improver	substances added to soil to maintain or improve its physical properties or to increase soil biological activity
VnA	valtioneuvoston asetus, Decree of the Government

1 INTRODUCTION

Tampere Regional Solid Waste Management Ltd (later PJH) is having a new biowaste treatment plant built in Nokia, Finland. For more than 20 years, biowaste collected in Tampere region has been treated aerobically by composting. The compost has been mainly utilised in green construction/horticulture and landfill cover layers. From autumn 2020 on, the technology will change to anaerobic treatment, and biowaste will be digested in a biogas plant.

Anaerobic Digestion (AD) in a biogas plant is a well proven process. In anaerobic digestion, micro-organisms decompose organic matter (feedstock) in airtight digester tanks to produce biogas (Lukehurst 2010). Biogas consists mainly of methane (50–80 vol%) and carbon dioxide, the former used to produce energy and heat. Anaerobic digestion also produces a biologically stable organic product, the digestate. (Deublein D & Steinhauser A 2008, 89; Tambone et al. 2010).

Digestion technology can be divided into wet and dry digestion. In wet digestion the dry matter content of the feedstock is below 15 %, and in dry digestion between 20-40 %. The biogas process can be either mesophilic (35-40 ^{o}C) or thermophilic (50-55 ^{o}C), the latter enabling also the material hygienisation, when the handling time is long enough. The material, circumstances and technique affect the efficiency of the process (Tampio et al. 2018). The new plant in Nokia will use wet digestion to treat sludge and dry thermophilic digestion to treat biowaste.

Anaerobic digestion as technology is not new, but in biowaste treatment it is becoming more and more common, especially dry digestion. In Europe, the number of biogas plants doubled between 2009 and 2016, and reached 18 202 installations in 2018. In 2015 biogas sector contributed with 5.5 Mtoe to the European electricity production, a share of 7% of the total renewable electricity production. (Beggio et al. 2019; EBA 2019)

Anaerobic digestion is an attractive technology for several reasons. It has a positive energy balance, possibility to stabilise organic matter and potential for inactivating pathogenic micro-organisms. The reduction of sludge handling requirements, robustness of the process and mitigation of greenhouse gas emissions make the technology increasingly interesting (Magri 2018).

The AD technology answers to the aims of bioeconomy based on renewable natural recources. Utilising waste to produce biogas and fertiliser products can help in fighting resource scarcity and rising prices of natural resource. Resource efficiency can also offer new competitive advantage (Suomen biotalousstrategia 2014).

Bioeconomy has been involved in European strategies already for some years. European Union published a Bioeconomy Strategy in 2012 and a Circular Economy Package in 2015, both promoting bioeconomy (Seppänen, Laakso & Luostarinen 2018). Many strategic objectives have been set in European countries to support a more resource-efficient economy based on the sustainable production of bio-based products (bioenergy and biomaterials) from renewable biomasses. Anaerobic digestion of sewage sludge, biowaste and manure has been evaluated as one of the most energy-efficient and environmentally friendly technologies for bio-energy production, organic biodegradable waste valorisation and potential recovery of valuable nutrients, which are concentrated in the remaining digestate (Vaneeckhaute et al. 2017).

Finland has its own Bioeconomy Strategy drawn up by the Finnish ministries of Agriculture and forestry, Economic affairs and employment and the Environment (Suomen biotalousstrategia 2014). Bioeconomy is one key area also in The Finnish National Waste Plan, which lays down the objectives and measures for waste management and prevention in Finland to 2023. One of the targets is to increase the use of fertiliser products made of recycled ingredients (Valtakunnallinen jätesuunnitelma 2018).

Current issues such as global warming, demand for renewable energy, landfill tax on organic waste, demand for organic fertilisers, high fossil fuel prices, pollution of the environment and legislation relating to organic wastes all influence the increasing levels of investment in anaerobic digestion (Lukehurst 2010).

The main target of the new biogas plant is to produce biogas, which will be utilised as fuel in transportation. The other aim is to utilise also the second output of the AD process; the digestates produced will be used as fertilisers and soil improvers. The digestates contain not just nutrients, but also important organic material. They can improve soil quality by increasing soil biological activity and humus content, improving soil water and nutrient retention capacity and restraining soil condensation and nutrient runoff (Seppänen et al. 2018). These fertiliser products can be used in agriculture, horticulture and land restoration.

Earlier the technical approach for digestate processing focused on nutrient removal practices similar to treatment of waste water. Currently the challenge for anaerobic digestion plants is to achieve optimal recovery and recycling of nutrients from the digestate. The former waste problem could be turned into an economic opportunity, when digestate is turned into marketable products. (Vaneeckhaute et al. 2017) However, with storage and transportation costs, currently there are mostly costs for the producers.

The circular economy relies on demonstrating the quality and environmental safety of wastes that are recovered and reused as products. Concerns of product safety need to be tackled by using engineering means on technical safety (Longhurst et al. 2019). Defining digestate quality and the role of the positive lists of input feedstock is crucial in ensuring the economic viability and environmental safety of digestate use (Beggio et al. 2019). The quality requirements can be different based on how the digestate is marketed; whether the digestate is sold as such, refined further at the plant or sold to a third party to handle the marketing. In all cases, it is important to know the quality of the digestate.

Longhurst et al. (2019) have studied declassifying quality-assured composts and anaerobic digestates prepared from source-separated biodegradable materials as wastes, which is legally needed for their marketing. Their study explored issues of potential human, animal and environmental risk. It was seen, that considerable weight of evidence was required to prove the safety of these products

(Longhurst et al. 2019). Managing digestates has to take into consideration the quality of the digestate and techniques and processes required to meet the specific regulatory and quality requirements (Peng & Pivato 2019).

Legislation and regulations concerning biowaste management, biogas production and fertiliser products are complex. The legislation covering fertiliser products and organic farming are being renewed, and need active follow-up from the operators in the field.

The markets of fertiliser products still have many challenges. Legislation with strict nitrogen and phosphorus fertilisation levels can cause technical barriers; high nutrient content can be a restriction in the areas with eutrophication risk. Practical complications are caused by large volume, and economic complications by high transportation and storage costs (Vaneeckhaute et al. 2017). The market acceptance (e.g. risk for food safety) is one important obstacle in agricultural use (Peng & Pivato 2019).

This study concentrates on the quality of the digestates from the dry digestion of biowaste. The regulatory requirements, feedstock and digestate quality and market situation were studied. To improve the interest towards the fertiliser products made of the digestates, it is recommended that Tampere Regional Solid Waste Management ltd builds either a quality protocol or a quality management system for the new biogas plant.

2 SCOPE

For the new biogas plant to operate in a sustainable manner and have environmentally and economically positive impacts, it should be able to produce not just biogas but also fertiliser products to promote nutrient cycling.

The objective of this study is to find out the regulatory framework concerning digestate and their utilisation as fertilisers. Only by knowing the framework, and the minimum and maximum requirements of fertiliser products, is it possible to aim at producing a marketable fertiliser product.

To produce quality digestates, it is important to know the quality parameters of the feedstock and the resulting digestate. To be able to sell them as products, it is essential also to know the possibilities and requirements of the markets.

The target is to estimate whether the digestates produced at the Nokia biogas plant are suitable organic fertilisers. The results of the study will be used as material for quality assurance of digestates, which can help prove fertiliser product status, marketing of the digestate, and that way improving the sustainability and profitability of the facility.

3 MATERIALS AND METHODS

The main method used in this study is literature review. First, the legislation and regulations of the biogas production and fertiliser product field was reviewed both in European and national level. The essential parts are summarised in chapter 4.1. Both the producer's and the user's side were studied, because without knowledge of the application, it would be hard to market the fertiliser products and guarantee their success in the markets. Consideration was given also to the regulation on organic farming, because that is assumed to be the most potential customer segment for the digestates.

3.1 Comparison of quality parameters

The known quality parameters of the feedstock of the new biogas plant were compared with the values found in the literature. Especially similar feedstocks were searched for, namely source separated biodegradable waste, because it was found, that values with different feedstock (e.g. manure) have great variation. The results are summarised in chapter 4.4.

The quality parameters of digestates were studied using literature review. Found values for whole, solid and liquid digestate were compared with the calculations of the biogas plant provider and estimates of an earlier research on biowaste in Tampere region. Results of the comparison presented in chapter 4.5 were used in making recommendations about the utilisation of the digestates.

3.2 Products and markets

To prepare for the marketing of digestates as organic fertiliser products, regulatory product requirements were studied both in national and European level. Previously conducted market researches were studied and challenges for market success were looked for. The findings are listed in chapters 4.6 and 4.8.

To improve the quality of digestate and assure its success in the market, a qualitative research to similar European biogas facilities was planned. A questionnaire was sent in November 2019 by email to 18 biogas plants producing digestate for fertilisation purposes. Replies were asked by email or Skype interview. Unfortunately, we got no replies. Therefore, utilisation of shared good practices in the new Nokia biogas plant was not possible. Conducting the same questionnaire in Finland was not done, because the operators sell their products to the same national markets, and therefore it was thought the replies would be affected by the competitive situation.

3.3 Quality management

Different methods to do quality assurance were studied. Especially the new national Quality Management System Lara was studied in order to find requirements that have to be taken into account at the new Nokia plant. The quality assurance methods in use in Finland are discussed in chapter 4.7.

The results of the study were used to make recommendations on the use of digestates. The information gathered will be utilised as quality assurance material once the biogas plant starts operation. The purpose of the quality assurance material is to help in justifying the end-of-waste status of digestate, in applying for quality labels and in marketing the fertiliser products.

4 RESULTS AND DISCUSSION

4.1 Regulatory framework

Regulations concerning fertiliser products are varied. The topic can be assessed from different angles, namely from the point of view of raw material, production or the product. Also the markets, transportation, costs and use in agriculture have to be considered.

By legal definition, fertiliser product means fertilisers, liming materials, soil conditioners, substrates, microbe products and by-products used as fertiliser products as such. Fertilisers are substances and products intended for promoting plant growth or improving the quality of the crop. Their impact is based on nutrients or other beneficial substances. Soil conditioners are substances added to soil to improve its physical properties or to increase soil biological activity. (Laki 539/2006)

The production of organic fertiliser products is steered both in EU and national level regulations, which give the minimum nutritional requirements as well as the maximum limits of harmful substances. The regulations protect the quality of fertiliser products and foodstuff and promote the use of recycled fertilisers. (Tampio et al. 2018)

According to Environmental Protection Act Annex 1, a biogas plant is considered a facility subject to an environmental permit. (Laki 527/2014) In addition, the facility approval of Finnish Food Authority is required. Several Acts and other regulations can affect the production and products. The legislation steering the production, marketing, storage, use and handling of fertiliser products is presented in figure 1.

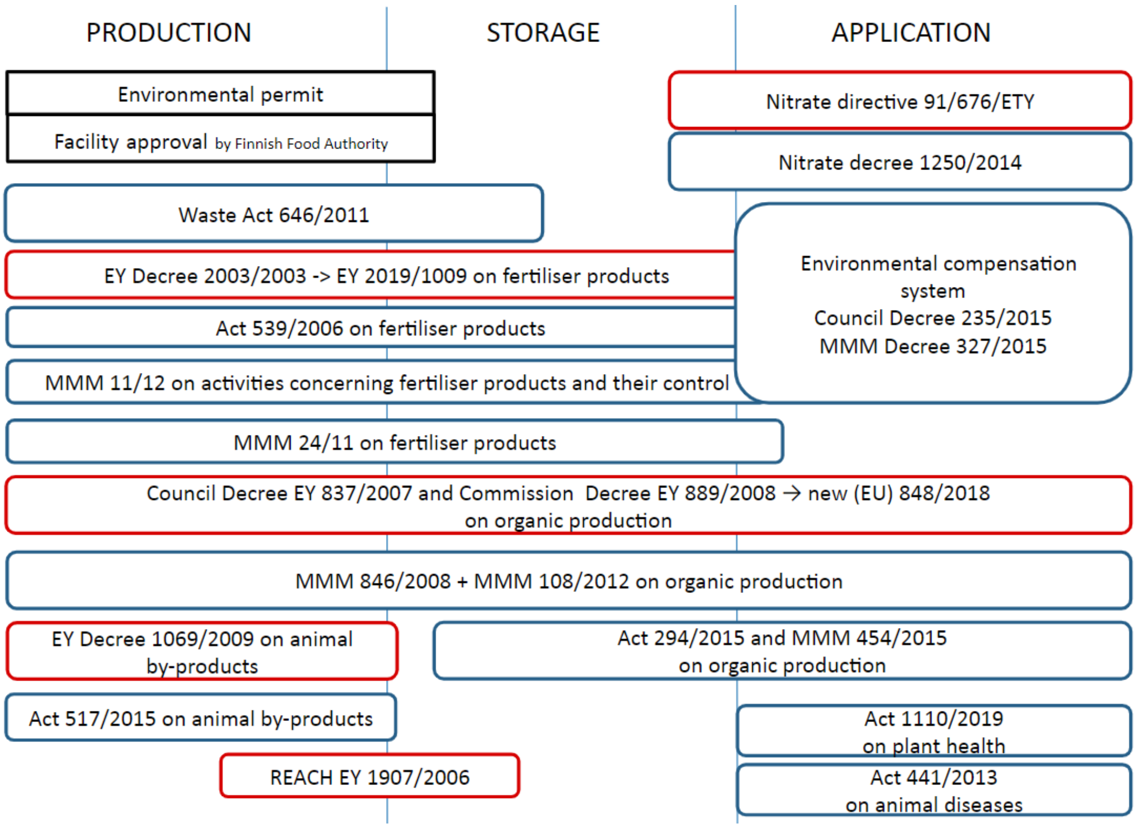

FIGURE 1. Regulations concerning fertiliser products
(--- European --- Finnish)

4.1.1 Waste or a product

When considering the regulatory framework related to digestates and their use as fertilisers, it is first important to define whether the digestate is waste or a product. Waste is defined in the Finnish Waste Act as any substance or object which the holder discards, intends to discard or is required to discard. (Laki 646/2011)

Food waste in general is defined as materials for human consumption that are discharged, lost, degraded or contaminated. Food waste is composed of organic waste and leftovers from residences, restaurants, cafeterias, canteens and markets. Comparable waste from food processing and biodegradable garden and park waste are also included in the definition of biowaste. (Asetus 179/2012; Peng & Pivato 2019)

The demand of digestates on the fertiliser markets depends on the digestate's legal status. Either in EU level or nationally it is possible to define End-of-Waste criteria, which ends the waste status of a material and forms a new product. (Tampio et al 2018; Beggio et al 2019) Until these days, no criteria for organic materials existed. Ending the waste status can also be handled by consideration of the environmental authority, who evaluates the nature of the material (Tampio et al. 2018).

Ending the waste status through case-by-case evaluation is based on the definition of waste. Waste Act 5 § sets the grounds for a substance or object no longer being waste:

1. it has undergone a recovery operation;
2. it commonly used for a specific purpose;
3. there exists a market for it;
4. it fulfils technical requirements and meets the existing regulations applicable to similar products; and
5. its use will not cause hazard or harm to human health or the environment. (Laki 646/2011)

Established case law verifies that using a case-by-case solution is possible, if no corresponding EU or national level regulation exists. The Finnish Ministry of the Environment has published a memo (2019) regarding the national case-by-case End-of-Waste decision making. It describes the assessment criteria the operator has to perform to the authorities when hoping to end the waste status of a product. Significant information is at least the following:

- waste feedstock, its origin, features and quality
- utilisation process
- quality of the processed material
- suitability of the material to intended use, possible limitations, markets and demand
- own-check system and quality assurance
- fulfilment of REACH and product requirements
- assessment of health and environmental risks of intended use of material

(Ympäristöministeriö 2019).

The quality control of the material is especially meaningful in assessment of ending the waste status. All phases of the process and production chain, that can affect the quality control, should be described. (Ympäristöministeriö 2019) Digestate failing to comply with the quality protocol is classified as waste and needs to be managed as waste (Peng & Pivato 2019).

4.1.2 European legislation

The Decree (EY 2003/2003) on fertiliser products has been the valid regulation steering the production, use and marketing of fertiliser products. During 2018-2020 the EU legislation on fertiliser products has been modernised to add safety requirements and harmonise the marketing (Tampio et al. 2018).

The new Decree (EU) 2019/1009 on fertiliser products was given in June 2019, and it will be applied from 16.7.2022 on. The new Decree covers also organic fertiliser products, which were not included in the previous Decree (EY 2003/2003). In the future digestate is allowed to be sold and used on the EU market as organic fertiliser under a CE certification. With CE-labelling come quality and safety requirements both for products and feedstock (Tampio et al. 2018; Beggio et al. 2019; Ympäristöministeriö 2019).

In the future, the operator can decide whether it wants to follow the EU Decree or the national regulations. If digestate with waste origin fulfils the CE-labelled requirements of the new Decree (19 article and appendix II) it can be considered not to be waste anymore. (Ympäristöministeriö 2019)

The CE-labelled fertilisers will replace the EY type designation list of fertilisers. The new Decree also defines new product categories. Organic fertiliser products can fall in four different categories: solid or liquid organic fertiliser, organic soil improver or mechanical blend of fertiliser products. (Tampio et al. 2018)

Positive lists of input feedstock are used to control the influence of anaerobic digestion substrates on the variability of digestate characteristics (Beggio et al

2019). The new Decree (EU) 2019/1009 lists the possible input materials for each fertiliser product category. These are discussed in more detail in chapter 4.6. (EU Decree 2019/1009). If animal by-products not intended for human consumption would be used as feedstock, the Decree on Animal By-products EY1069/2009 should be considered. (Tampio et al. 2018)

In EU level the producer of fertiliser products also needs to take into account the REACH Decree 1907/2006 on registration, evaluation, authorisation and restriction of chemicals (Tampio et al. 2018). The EU commission has been preparing changes to REACH Decree's appendix V during 2019. The plan has been to add digestates to list that would release them from registration obligation, with similar reasoning to compost and biogas. Registration obligation might still concern post-treated digestates and reject waters (Ympäristöministeriö 2019).

4.1.3 National legislation

Essential national law considering digestates is Finnish Fertiliser Product Act. The Act aims at ensuring all fertiliser products placed in the markets in Finland are safe, of good quality, and suitable for plant production. It also aims at utilising suitable by-products and providing enough information about products to their users. The Act applies to manufacturing, marketing, use, transport, import and export of fertiliser products and their ingredients. (Laki 539/2006)

Closely related are the Decrees of Finnish Ministry of Agriculture and Forestry on Fertiliser products (24/11) and on Activities concerning fertiliser products and their control (11/12). They regulate the raw materials, type designation list and the requirements for quality, labelling, packaging, transporting, storage, usage and other requirements and the raw materials used in fertiliser products. (MMM 24/11; Tampio et al 2018) The national regulations incorporating the new Decree (EU) 2019/1009 are being updated. The Government has given its suggestion to the Parliament in March 2020 (Eduskunta 2020).

In production of plant based fertiliser products, the requirements of the Act on Plant health (1110/2019) need to be considered. With animal based raw materials, also demands of the Act on animal diseases (441/2013) and the Act on animal by-products (517/2015) need to be checked. (Ympäristöministeriö 2019) The plant in Nokia will not accept animal by-products and class 3 biowaste.

The production itself is regulated in the Acts mentioned earlier. An important monitoring system is self-surveillance or own-check system of the facility, which applies to all producers of fertiliser products. A permanent system, based on the HACCP (Hazard Analysis and Critical Control Points) principles, is called own-check in the Finnish food business and quality assurance in the feed business (Ruokavirasto 2019). The system helps operators to manage the risks related to their operations and meeting the requirements laid down in foodstuff system of operators. (MMM 11/2012; Tampio et al. 2018)

The operator needs to maintain detailed data of the raw materials, production, storage and sales. The operator is required to inform The Finnish Food Authority yearly of the production quantities, product names and raw materials of fertiliser products. (Laki 539/2006)

The dry digestion process in Nokia fulfils the national handling requirements for biowaste. It suits for handling of biowaste from households and restaurants. When food waste from markets and industry is used as feedstock, it needs to be hygienised in 70 ^{o}C for 60 min (diameter <12mm) or digested thermophilically in closed container in 55 ^{o}C for two weeks' time. (MMM 24/11; Tampio et al. 2018)

The hygienised digestate formed in biogas process can be used as such or mechanically dried in fields and gardens as soil improver. After aerobic composting it can also be used as raw material for substrate, if the compost fulfils the requirements of fertiliser products and maturity requirements of soil improver. (Ympäristölupa LSSAVI/5359/2018)

It is not enough for the operator to be aware of the regulations on production and sales of fertiliser products. Attention should be paid also to the legislation covering the use of these products. The Decree of the government (2014/1250) on limiting emissions from agriculture and horticulture executes the European directive (91/676/ETY) to protect water bodies from agricultural nitrates. The aim of this ‘nitrate directive’ is to prevent and reduce the emissions from manure and fertilisers. It applies to the use, storage and application of fertiliser products (VnA 1250/2014; Tampio et al. 2018).

Both the Government (Vna 235/2015) and the Ministry of agriculture and forestry (MMM 327/2015) have set Decrees on the environmental compensation system of agriculture. Those set limits to the use of nitrogen and phosphorus in fertilisation of fields. In practice, these regulations have a big influence on the use of fertiliser products (Tampio et al. 2018).

The waste feedstock, emissions, process monitoring, risk management and environmental obligations of a biogas plant are supervised by the environmental authorities (Ympäristöministeriö 2019). Finnish Food Authority (Ruokavirasto, former Evira) supervises the production, marketing, transportation, storage, use and handling of fertiliser products. It also maintains the supervision register of the operators (Tampio et al. 2018).

4.1.4 Organic production

When the operator intends to produce fertiliser products that are suitable for use in organic farming, it is important to know also the regulations concerning organic farming and products. Organic production is based on the use of renewable and local natural resources. Nutrient recycling is favoured, but also fertilisers and soil improvers outside of organic production system are permitted when justified. These additional fertilisers are listed in European Commission Decree (EY) 889/2008 Annex 1. They can contain additional requirements for the content, origin of the raw material, production method and use (EY 889/2008; Tampio et al. 2018).

Household waste is an approved additional fertiliser in organic farming, when it is source-separated and composted or anaerobically fermented to produce biogas. Only household waste with plant and animal origin is accepted, and only when it is produced in closed and approved collection system (EY 889/2008). Organic waste from foodservice and catering is included in the definition of household waste (MMM 454/2015).

Evira guide (18219/6) of organic production explains the minimum requirements of the Council Decree (EC) 834/2007 and Commission Decree (EY) 889/2008, and they should be followed in all organic production. These Decrees are implemented in Finland with the Act 294/2015 on Surveillance of organic production and the Decree 454/2015 of the Finnish Ministry of Agriculture and Forestry on organic production (Evira 2018).

The European regulation on organic production is under renewal process. The new basic Decree (EU) 2018/848 has been set, and will be applied from 1.1.2021. The statute for incorporation into national legislation, including the allowed fertilisers and their limitations, is yet to be published. Following that, the national regulations will be updated (Maa- ja metsätalousministeriö n.d.).

Organic farms need to have an up-to-date organic scheme, which includes description of the fertilisation procedures. If additional fertilisers are needed, the scheme lists products, their quantities and reasoning for their use. Fertilisation in organic farms is regulated also by the legislation on fertiliser products (Evira 2018).

To be able to use organic labels, the farmer needs to join the organic production surveillance system. There the farmer commits to follow the legislation on organic production. In national markets the Finnish Food Authority can grant a product label in an advisory organic fertiliser catalogue (Tampio et al. 2018).

4.2 Nokia biogas plant

The biogas plant being built in Koukkujärvi Nokia will start operation in autumn 2020. The concept of the plant is based on a combined process, where biowaste is managed in a dry anaerobic process and wastewater sludge in a separate wet anaerobic process. This study concentrates on the digestate from the dry handling process of biowaste.

4.2.1 Process input

The dry anaerobic process line manages both source-segregated biowaste from households, markets and industry, and garden waste. The dry digestion process is estimated to have feedstock of max 24 000 tons/year, constituting of fractions shown in table 1 (EcoProtech 2019).

TABLE 1. Designed input in dry digestion process (Ympäristölupa LSSAVI/5359/2018)

Waste fractions	**Waste code**	**Input load (t/a)**	**% TS**
biowaste, households	20 01 08	16 000	29
biowaste, commerce and industry	20 01 08 / 16 03 04 / 02 06 99	4 000	37
garden waste (e.g. branches and raking waste	20 02 01 / 02 01 03	4 000	35
Sum		24 000	

The environmental permit of the biogas plant allows the use of stumps (17 02 01), branches and green waste (20 02 01) and vegetation/plant waste (02 01 03) as supporting material in composting following the dry digestion. If needed, the waste accepted to dry digestion can be used also in wet digestion, but not vice versa. (Ympäristölupa LSSAVI/5359/2018)

4.2.2 Production process

The dry digestion process uses biowaste and green waste to produce biogas and digestates as shown in figure 2. The digestion process is divided in pre-handling, processing and refining. Accepted biowaste is first unloaded from trucks to a receiving bunker (170 m^3).

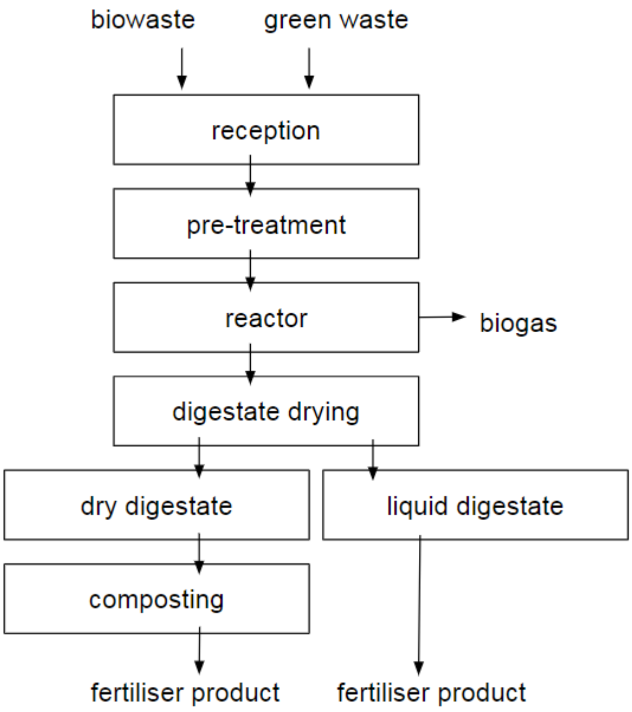

FIGURE 2. Description of the dry digestion process of biowaste (EcoProtech 2019)

Biowaste is moved to a pre-handling process with a crane and a grab. In pre-handling, the raw material is processed so, that it suits the actual process. Bio-waste is crushed and the bags teared open. The capacity of the crusher is minimum 17 tons/hour. Crushing adjusts the particle size optimal for the process, as well as increases the surface area of the material to facilitate anaerobic digestion. Crushed material goes through magnetic metals separation to dry anaerobic reactor. The rest of the rejects will be sieved off in the end of the process, after composting. (Tampio et al. 2018; EcoProtech 2019)

Packed biowaste from markets and industry can be handled separately with a biowaste compactor to remove packaging material before the anaerobic process. In compression, the organic material is separated into a paste, which is moved into a storage tank. From there it is pumped further to dry digestion reactor. (EcoProtech 2019)

A separate crusher will break woody materials, green waste and in wintertime help frozen biowaste loads handling. These materials are fed to the receiving bunkers by a wheel loader. Liquid wastes such as milk, grease and oils and the liquid biowaste from the compactor can be stored in separate tanks and fed to either dry or wet process based on the material quality and process situation. From receiving hall and pre-handling, the material is conveyed by belts via feeder to a mixer, where water is added to material for optimal dry matter content. Feeding to reactor is automatic and continuous. Dry reactor (MARTIN TTV Thöni reactor, model TTV2250) contains a steel reactor with integrated heating system and slowly rotating horizontal mixer with several blades. The mixing blade rotates close to reactor bottom ensuring good mixing of material. (EcoProtech 2019)

Process is based on anaerobic, thermophilic dry digestion in temperatures 53 - 55 °C, with average dry matter content above 25 %. The average retention time is 19 days. These ensure the outcoming digestate is hygienisized, and unwanted plant seeds and micro-organisms are destroyed. (EcoProtech 2019)

Hydraulic pump in the other end of the reactor transfers the digestate to the next process phase, 2-phase drying. First vibrating sieves (0.8 – 1.2 mm diameter) and their inclination removes liquids. In the second phase a screw press separates the rest of the liquids from solid digestate. The reject water flows to a container, from where it is pumped to sedimentation container. The dry matter content and processing time can be adjusted with the sieve size. If needed, polymers can be added to enhance water separation. (EcoProtech 2019)

The reject water from dry process can be used as a liquid fertiliser in agriculture or added to the composting process to add moisture. Water can also be recycled to process water into the wet digestion, where it can enhance gas production. The liquid phase can also be led to wastewater treatment plant, possibly with pre-drying to reduce solid matter content, which in reject water is about 10 %. The size of the storage container for liquids is 3000 m^3, which equals approximately three months storage requirement. (EcoProtech 2019)

The solid digestate is moved by a wheel loader to closed composting tunnels, which have aerated floor structure and over-pressurised process to improve composting. Digestate from dry process are composted separately from the wet process digestate. Supporting material is added to digestate. Retention time in the composting process is approximately three weeks. The composted material is moved by a wheel loader from the tunnels to screening line, which has magnetic metal separation and air drum separation for removal of plastic waste. After this treatment, the material stability level is very mature and equals Rottegrad test class 4. It can be further composted in the after-composting field. (EcoProtech 2019)

4.2.3 Process output

The products from the dry digestion process are compost 2871 tons/year (51.1% TS) and liquid fertiliser 11 500 tons/year (10.0 % TS) (EcoProtech 2019). Appendix 1 shows the mass balance of the dry digestion process.

The ready compost is estimated to contain 5.67 kg/t nitrogen, 3.97 kg/t phosphorus and 2.85 kg/t potassium. The liquid fertiliser is estimated to contain more nitrogen (7.84 kg/t), but less phosphorus (0.89 kg/t) and approximately the same amount of potassium (2.95 kg/t). (EcoProtech 2019)

4.3 Digestate management

Digestate can be in the form of whole, liquid or solid digestate, or it can be further aerobically treated to form compost (Peng & Pivato 2019). Majority of AD facilities recycle the digestate to local agriculture as an organic fertiliser. The European Nitrates Directive regulates the application of organic materials to agricultural land; spreading of digestate to land is controlled and dependent on location, season and crop demand. Transportation and storage can cause significant costs and other challenges. Digestate must therefore be carefully managed to make sure the maximum benefit is achieved (Wrap 2012).

The key aims of the digestate enhancement techniques are to

- increase the value
- create new markets
- reduce the dependence on land application, and
- potentially reduce the operating cost of the facility.

(Wrap 2012)

Koukkujärvi facility is designed to produce biogas. The secondary aim is to produce a quality digestate preferable suitable for fertilisation in organic farming. Digestate refining is often required. Refining is an important phase of the process, because that ensures the product fulfils the quality and safety requirements and nutritional values set in the legislation. Different enhancement techniques with their benefits and drawbacks are summarised in table 2. Most biogas facilities, including the new Nokia plant, use hygienisation and composting in refining (Tampio et al. 2018).

TABLE 2. Enhancement techniques for digestates (modified from Peng & Pivato 2019).

TECHNOLOGIES	BENEFITS	DRAWBACKS
WHOLE DIGESTATE		
Thickening	Digestate of 5-10% DM; reduce the volume	Add poly-electrolyte
Dewatering	Digestate of >18% dry solids; reduce transport costs	Add flocculants; energy consuming
Evaporation	Retain the nutrients and a proportion of the moisture	Acid dosing
Reed beds	Dewatering the digestate to 30-40% dry solids; reclaimed water	Long period
Biological oxidation	Reduce BOD and ammonia; biological sludge can return as feedstock for the digester	High operation costs

SOLID DIGESTATE

Composting	Break down organic matter; convert ammonia to nitrate	Quite long time
Thermal drying	Produce 57.5 - 92.5 % DM; use as organic fertiliser or energy recovery	Ammonia loss
Incineration	Possible autothermic operation; ash for concrete production and phosphorus recovery	>40% DM high calorific value required
Pyrolysis	Recovery syngas; reduce 70% of the mass; production of biochar	Dry pelletized form required

LIQUID DIGESTATE

Membrane purification	Direct discharge; nutrient recovery for concentrated liquors	Concentrate disposal; fouling; high energy requirement
Surface scraped heat exchanger	Reduced volume; concentrate nutrient rich product	Acidic product may limit available land
Struvite precipitation	Recovery of struvite; struvite is recovered as easily handled pellets; prevents fouling	Contaminated with solids; market security
Ammonia stripping	Ammonia removing restriction on land application; concentrated ammonium sulfate as fertiliser	High temperature and pH
Algas pond/photo bio reactor	Produced algae which can either be sold or converted into biodiesel; removes CO_2 from biogas	Large surgace area; complex bioreactor control
Reed beds/wetland	Low power and opeartion cost; sanitization; stabilization; volume reduction	Large land area; long operational time (10-15 yrs)
Biological oxidation	Nitrified effluent as a fertiliser; reduced disposal cost; stabilization	High power consumption

4.3.1 Whole digestate

Whole digestate usually needs physical pre-treatment, such as thickening and dewatering, to achieve a higher dry matter content in order to reduce the volume and transportation costs. The whole and solid digestate can be applied on land in agriculture when it meets the biofertilisation criterion. It can also be a peat substitute and material for landfill cover or landscape restoration. (Peng & Pivato 2019)

Whole digestate formed in Nokia biogas plant is treated mechanically to separate solid and liquid digestate. Separation is done to achieve easier and cheaper handling and transport of separated fractions and/or purification of separated liquid fraction (Beggio G. & Pivato A. 2019).

In 2014 up to 95 % of the digestate produced in Europe was utilised directly in agriculture, but currently different processing technologies are becoming more common. Most utilised technology is separation either by screw press or centrifuge. Different membrane filtration techniques have become more popular in treating liquid phase, and digestate drying has become more attractive in Germany with subsidies granted to utilising excess heat in CHP-plants. (Seppänen et al. 2018)

Nokia plant will use screw press in mechanical separation. Digestate is pressed against cylindrical sieve, letting the liquid fraction separate through. Screw press technique is simple, and the efficiency can be adjusted by changing sieve mesh and pressing force. Investment and energy consumption of the method are low. (Seppänen et al. 2018)

Different separation methods were compared in ProRavinne report. The dry matter content (TS) of dry digestate after using screw press was on average between 20 and 30 %. (Mönkäre T. 2018b) Screw press has been found to give high separation efficiency; the screw press partitioned more dry matter, volatile solids, carbon, ash and phosphorus to the solid phase than to the liquid phase (Lukehurst 2010). Phosphorus separation, though, can be disturbed by small particles (0.5 mm diameter) ending up in the liquid phase. (Seppänen et al. 2018)

Separation creates two outputs, a liquid and a fibrous material, that need to be stored and handled separately. In solid-liquid separation, the nutrient ratio changes, but their usefulness is not affected (Tampio et al. 2018). The solid fraction is rich in recalcitrant organic matter, calcium, magnesium and often phosphorus, but nutrients are mostly organically bound. Soluble nitrogen, some phosphorus, potassium, organics and mineral salts are present in the liquid fraction. Using extraction techniques, soluble nutrients can be recovered from the liquid fraction (Vaneeckhaute et al. 2017).

4.3.2 Solid digestate

Separated solid fraction of digestate is more suitable for agricultural use than whole digestate, based on both logistical and agro-technical reasons. Solid digestate could be further composted, but it can reduce the nutrient value and has the potential to cause greenhouse gas emissions. (Peng & Pivato 2019)

Solid fraction of the digestate could also be treated by incineration, pyrolysis or thermal drying, as table 2 shows, but increased temperature results in lower phosphorus usability for plants and slower carbon break down in soil. Also nitrogen can evaporate. Advantages of thermal treatments are improved hygienic quality, lower level of harmful substances and easier transportation. (Tampio et al. 2018)

In Nokia biogas plant, the solid digestate is composted in closed tunnels. Composting process requires supporting material such as branches and raking waste to achieve a required C:N ratio and to control the process gases. The pH and temperature change during composting, and they can be controlled by process management to decrease ammonium evaporation. The ammonium evaporating in composting process is collected by washers. According to Mönkäre et al. (2016) it can also be precipitated with sulphuric acid to form ammoniumsulphate. In composting process water is evaporated and leachate water with soluble nutrients is produced. (Mönkäre et al. 2016)

The composting technology is well known to the operator of the plant; composting in tunnels has been done since 2004. The operator has provided different compost products to the markets for more than a decade, and the position in the markets offers good possibilities also in marketing the new compost products. The storage capacity for the compost is good, and company’s own need in landfill cover layers will help in market fluctuations.

4.3.3 Liquid digestate

The liquid digestate can go through various nutrient recovery processes (table 2) to produce e.g. concentrated nutrients and purified water. The concentrated fraction can be applied as a liquid biofertiliser, and purified water can be recycled within the process or treated in wastewater treatment plant. (Peng & Pivato 2019)

In Nokia plant, liquid digestate is stored in a tank, where solids sedimentation occurs. At least in the beginning, no other treatment is planned. This part of digestate can be applied in agriculture, either as such or mixed with other products. If it is meant for organic farming, also the additional fractions need to be suitable for organic farming.

Vaneeckhaute et al. (2017) have compared technologies for the recovery of macronutrients from digestate. From technical perspective, further fine-tuning is required for all technologies in order to minimise operational costs and produce high-quality fertilisers. Attention should be paid to the quality of the remaining effluent flow after nutrients recovery. As their conclusion, the best available and most established technologies for nutrient recovery from digestate in terms of technical performance and fertiliser marketing potential are struvite precipitation, ammonia stripping and adsorption using a stripping column. (Vaneeckhaute et al. 2017)

4.3.4 Storage of digestate

Digestate is produced throughout the year and must be stored until the growing season. The length of the storage period required depends on geographical area, soil type, winter rainfall, crop rotation, and national regulations governing digestate application. (Lukehurst 2010)

Storage of fertiliser products has to be solved with both the producer and the customer. The operator needs to have suitable facilities and equipment to produce, store and transport fertiliser products. Adequate care and safety is required in handling, use, transportation and storage of the raw materials and products to prevent harmful health, safety and environmental effects. (Laki 539/2006)

For unpacked organic fertiliser products, 12 month's storage capacity is common, both for liquid and solid fractions. Besides environmental permit, regulations on storage and handling are given in Decree 24/11 (Tampio et al. 2018). The environmental permit of the Nokia biogas plant allows storage of max 500 tons for feedstock and max 1700 tons for the additional fractions (branches, green waste). For digestate products, the maximum for compost in windrows is 29 000 tons and for liquid digestate 5300 m^3. The storage container for liquid digestate (3000 m^3) offers storage capacity for approximately three months' production, which means that additional storage capacity has to be organised outside growing season (Ympäristölupa LSSAVI/5359/2018).

Fertiliser products' storage should not affect their composition. Moisture or microbiological contamination cannot weaken the quality, and the storage has to be separate from the raw materials. Products sold unpacked have to be covered for transportation, if there is possibility of harm or danger to other traffic or the environment. (MMM 24/11)

The storage capacities of the customers vary. In agriculture, the storage requirements for unpacked organic fertiliser products are set in 'Nitrate directive' 1250/2014. (Tampio et al. 2018) It forbids spreading nitrogen containing organic fertiliser products during 1.11.-31.3., which means storage time of at least six months. In practice, 12 month capacity is recommended. Products with >30 % dry matter content (such as compost) can be stored in windrows/stacks on fields, but not between November and January. (VnA 2014/1250; Mönkäre et al. 2016) Suitable storage facilities mean water tight storage with adequate capacity. With liquid fertiliser products, attention should be paid to covering the storage to prevent odors and evaporation of ammonium (Tampio et al. 2018).

Packed fertiliser products are also regulated in Decree 24/11. The package has to be tight and sealed in a way, where they are broken when opened. Maximum package size is 1000 kg. Also with packed products, the composition has to stay stable during storage. Granulated fertiliser products may absorb moisture during storage, which can cause difficulties in spreading. Liquid products might freeze during winter, which has led to a recommendation of above 0 ^{o}C storage temperature. (Tampio et al. 2018)

4.3.5 Transportation and spreading

When planning the sales of fertiliser products, transportation and use of products need to be considered. Whether the products are sold directly to the end users or via a third party, distance and cost of transportation and the quality issues have to be solved. Organic fertiliser products cannot be applied to the field from November to end of March, nor to frozen, snow covered or water saturated soil (Tampio et al. 2018).

Dry fertiliser products can be transported to the customer by a truck or a tractor. Transportation of granular products is more cost efficient, because there is more nutrients in relation to the weight than compost and sludge like products. Solid fertiliser products can be applied to the field using spreading devices of dry manure. (Tampio et al. 2018)

Liquid fertiliser products can be transported by a tank truck, sludge tank or smaller amounts in containers. The product can be unloaded to a storage container or directly to sludge tank. The liquid products can be applied to the field using devices of spreading sludge or spraying of pesticides. (Tampio et al. 2019)

The application of dry products is limited by the amount of phosphorus, and the liquid products by the amount of soluble nitrogen. The Decree 5/16 by the Ministry of Agriculture and forestry set a limit of 325 kg/ha of soluble phosphorus in agriculture for the period of five years. (Tampio et al. 2018) The limit for the total nitrogen in Decree 1250/2014 does not apply to organic fertiliser products. Instead, limits for soluble nitrogen are used. The maximum amounts are given based on the vegetation type. In practice, the fertilising practices are defined by the terms of the environmental compensations system (Mönkäre et al. 2016; Tampio et al. 2018).

To guarantee a good fertilisation procedure without local over-fertilisation and maintain high groundwater qualities, good fertilising practice may require transportation of nutrients between areas (Gienau, Bruss, Kraume & Rosenberger 2018). The situation in Tampere region is handled in chapter 4.8 covering market situation.

4.4 Feedstock quality

The composition and quality of digestate is strongly dependent on the infeed biomasses and applied treatment conditions (Magri 2018; Tambone, Orzi, Zilio & Adani 2019). Digestate contains all material that has not biodegraded and converted into biogas within the process. It means that all nutrients and contaminants present in the feedstock will remain in the digestate (Lukehurst 2010). Therefore, it is important to know the quality of the feedstock to be able to guarantee a good quality digestate. Positive lists of input feedstock are used to control the influence of AD substrates on the variability of digestate characteristics (Beggio et al. 2019).

4.4.1 Nutrient values of feedstock

The environmental permit of the Nokia biogas plant lists the following wastes as accepted feedstock materials in the dry digestion process: biowaste from households, commerce and industry, stumps, branches and garden waste, raking waste and other green waste. (Ympäristölupa LSSAVI/5359/2018)

It is agreed, that biowaste contains lots of nutrients and organic matter, but literature reviews show, that feedstock nutrient values vary a lot. Digestate contains all the nitrogen, phosphorus and potassium present in the feedstock, but the actual nutrient content is highly dependent on the type of feedstock processed (Wrap 2012; Seppänen et al. 2018).

The raw material potential of source segregated household biowaste, packed biowaste from shops and biowaste from business was estimated in studies of Mönkäre et al. (2016) and Lukehurst, Frost & Al Seadi (2010). Their results can be seen in table 3.

TABLE 3. The raw material potential of biodegradable waste (FW= fresh weight, DM=dry matter)

Feedstock	Total solids	Total nitrogen	Total phosphorus	Source
food leftovers	9 – 18 *kg/m^3FW*	0.8 – 3 *kg/m^3 FW*	0.7 *kg/m^3 FW*	Lakehurst et al. 2010
biowaste	25 – 35 *% TS DM*	2 – 3 *% TS DM*	0.5 *% TS DM*	Mönkäre et al. 2016
raking waste	29 *% TS DM*	2.8 *% TS DM*	0.11 *% TS DM*	Mönkäre et al. 2016

Two years later Mönkäre (2018a) analysed the nutrient content and other features of different biowaste collected in Tampere region. The comparison with similar biowaste in Helsinki and UK in table 4 show, that mean values are in similar range for most parts. Biowaste in Tampere contained more phosphorus in this study than biowaste in Helsinki and UK. The Finnish heavy metal concentrations were higher than in UK with copper, zinc and iron.

TABLE 4. Quality of feedstock (modified from Mönkäre. 2018a)

	unit	BIO1 (household biowaste)	BIO2 (commercial biowaste)	leaves	branches	biowaste, Helsinki *	food waste, UK *
N_{tot}	g/kg	27.2	21.6	9.4	8.9	27	30.7
$N_{soluble}$	g/kg	2.96	1.72	0.3	0.3	2.5	9.6
P_{tot}	g/kg	6.0	2.9	1.2	1.2	3.6	3.8
$P_{soluble}$	mg/kg	1400	1600	170	220	1300	1700
K	g/kg	9.5	9.1	3.3	6.2	10	9
Mg	g/kg	1.3	< 1.1	2.9	2.5	1.1	-
Cu	mg/kg	9.3	5.3	12	12.	10 - 11	4.9
Mn	mg/kg	37	17	330	220	-	-
Zn	mg/kg	60	20	82	96	100 - 180	28.2
B	mg/kg	< 21	< 21	< 20	< 21	-	-
Na	g/kg	4.6	4.9	0.15	0.18	-	-
S	g/kg	1.7	1.7	< 1.0	< 1.0	-	-
Fe	mg/kg	840	260	9500	5800	-	130
pH		4.1	3.7	5.4	6.7	-	5.1
EC	mS/m	272	285	25.2	23.4	-	-
TS	%	29	37	24.9	44.7	28.7	24.8
VS	%	90.4	96	60.7	71.3	89	93.9
specific weight	kg/m3	1000	1000	660	430	960	1064
C/N		19.3	21.1	26.8	31.4	19	15.3

* Mönkäre 2018a

In Proravinne study (Mönkäre 2018a), mass and nutrition balances of the biogas process and digestate were calculated. In dry digestion line, biowaste was processed together with garden waste. Table 5 shows, that most of the process feedstock is household biowaste, which contains noticeable amount of nutrients. It has to be noted, that the features vary between seasons, especially with garden waste (Mönkäre 2018a).

TABLE 5. Materials fed into biowaste process with their composition in mass (tons) (According to Mönkäre 2018a)

	household bio-waste	commercial biowaste	garden waste	sum
Mass (t)	16 000	4 000	4 000	24 000
Dry matter (t)	4 640	1 480	996	7 116
Organic matter (t)	4 195	1 421	605	6 220
N_{tot} (t)	126	32	9	168
P_{tot} (t)	28	4	1	33

Anaerobic micro-organisms can decompose all kinds of organic materials. Biochemical changes take place in anaerobic digestion, and those can affect the organic compounds and the availability of nutrients to crops. (Lukehurst 2010)

4.5 Digestate quality

In the study of Mönkäre (2018a), biowaste collected in Tampere region was digested, and the quality of the digestate was analysed. The results in table 6 show that household biowaste and packed commercial biowaste have similar nutrient content, whereas the additional compost materials are poorer in nutrients.

TABLE 6. Nutrient content of digestates (According to Mönkäre. 2018a).

	unit	BIO1 (household biowaste)	BIO2 (commercial biowaste)	leaves	branches
N_{tot}	g/kg	63.1	69.7	45.9	46.3
$N_{soluble}$	g/kg	29.2	41.4	7.64	19.7
P_{tot}	g/kg	18	16	8.3	15
$P_{soluble}$	mg/kg	330	410	100	200
K	g/kg	33	35	2.7	33
Mg	g/kg	4.8	4.8	2.4	6.5
Cu	mg/kg	99	85	60	66
Mn	mg/kg	1100	920	710	940
Zn	mg/kg	300	270	240	250
B	mg/kg	39	39	32	33
Na	g/kg	120	130	11	160
S	g/kg	8.2	6.7	3.8	4.2
Fe	mg/kg	94000	81000	54000	74000
pH		7.7	7.8	7.5	7.6
EC	mS/m	152	179	107	121
TS	%	2	1.9	4.6	2.2
VS	%	53	51.5	52.4	47.8
specific weigh	kg/m3	1000	1000	1000	1000

EcoProtect, the facility supplier of the Nokia biogas plant, has calculated nutrient contents for the digestates from the dry digestion process. The values in different stages of process are presented in Appendix 1. After mechanical drying, the solid digestate has a total solids content of 42 %. When it is composted with supporting material, some gaseous components are removed and the material is sieved for removal of impurities, the ready compost is estimated to have a total solids content of 51 %, which is in line with the literature values in Appendix 2. The solid digestate in Nokia is estimated to contain 5.67 kg/t nitrogen, 3.97 kg/t phosphorus and 2.85 kg/t potassium. Comparison with average central European values for biocompost (4.5 kgN/t, 2 kgP/t, 2.5 kgK/t), and the nutrient content of digestate and compost presented in table 7 show, that the estimates are higher for the new plant (EcoProtech 2019). Nutrient values for composts are higher than for digestate, except for the readily available nitrogen.

TABLE 7 Typical nutrient contents for digestate and compost

	Unit	Post-digestion compost *	Food-based digestate **	Green compost **	Green/food compost **
pH		7.6 -7.7			
Conductivity	mS/cm	2.5			
Total dry solids (DS)	%	34 - 58	4	60	60
Organic Matter	% of DS	41 - 63			
N_{tot}	kg/t	8.7 - 16.7	5	7.5	11
$N_{available}$	kg/t	0.5 - 2.6	4	< 0.2	0.6
Phosphate (P_2O_5)	kg/t	5.1 - 12.3	0.5	3.0	3.8
Potash (K_2O)	kg/t	7.2 - 21.1	2.0	5.5	8.0
Ca	kg/t	12.6 - 132.4			
Mg	kg/t	3.9 - 6.1	0.1	3.4	3.4
S	kg/t	<0.05 - 3.9			
Cd	g/t	0.1 - 0.2			
Cu	g/t	22.4 - 66.9			
Ni	g/t	6.6 - 13.5			
Pb	g/t	12.6 - 36.4			
Zn	g/t	42.4 - 102.81			
Cr	g/t	-			
Hg	g/t	0			
Source		*Target Renewables (2019)*	*Wrap (2016)*	*Wrap (2016)*	*Wrap (2016)*

* values of DS (dry solid content)
** values of FW (fresh weight)

After dry digestion and mechanical drying, the liquid digestate in Nokia has a total solids content of 10-11 %. Fertiliser value is estimated to be 7.84 – 8.43 kg/t nitrogen, 0.89 – 1.27 kg/t phosphorus and 2.95 – 3.17 kg/t potassium, depending on whether part of the liquid fertiliser is recycled to the wet digestion process as a booster or not. (EcoProtech 2019)

When compared with the results of presswater liquid fertiliser of Target Renewables (2019) in Appendix 2, nutrient content of liquid digestate in Nokia seems poor.

In general, the volume of the digestate produced is typically approximately the same as the feedstock volume, while the mass is reduced by approximately 15 % (Wrap 2012). Comparing nutrient values found in literature reveal large variation. Vaneeckhaute et al. (2017) studied 213 digestates from different (co-) digestion plants in Belgium during 2008-2011. They concluded, that the composition of digestate vary strongly according to the composition of the feedstock that is digested, next to the digester type and process parameters. The product quality ranges of unprocessed digestate are shown in Appendix 2. Hence, giving a standard composition of digestate is not possible (Vaneeckhaute et al. 2017). Peng and Pivato (2019) came to similar conclusion in their study. They characterised different forms of digestate from organic fraction of municipal solid waste (OFMSW) and food waste (n=30-135 depending on parameter). Their results are also presented in Appendix 2.

Digestate from separately collected OFMSW results significantly different from agro-industrial digestate only for a few of investigated features, namely parameters describing amendment and fertilising potential (lower VS, higher N_{NH4}, N_{tot}, P_{tot}) and environmental impacts properties (higher Pb, Ni, Cr_{tot} and Hg concentrations), found Beggio et al (2019) in their data comparison.

Essential features for defining digestate quality are nutrient content, pH, dry matter and organic dry matter content, unwanted physical and chemical impurities content (i.e. plastic and glass particles, heavy metals, persistent organic pollutants) and hygiene status (e.g. presence of Salmonella and/or Coliforms). Biological stability and phytotoxicity are also important aspects. The digestate could be categorized based on their properties as presented in table 8. (Beggio et al. 2019)

TABLE 8. Digestate categorization (According to Beggio et al. 2019)

Category	**Parameter**	**Unit**
Amendment properties	pH TS VS C_{tot}	- g TS/kg FM g/kg TS g/kg TS
Fertilising properties	N_{tot} P_{tot} K_{tot} EC	g/kg TS g/kg TS g/kg TS mS/cm
Environmental impact properties: chemical contaminants	Cd Pb Cu Hg Ni Zn Cr_{tot} PAH16	mg/kg TS mg/kg TS mg/kg TS mg/kg TS mg/kg TS mg/kg TS mg/kg TS mg/kg TS
Environmental impact properties: biological stability	VFA BMP	mg/l l biogas/kg VS

4.5.1 Organic amendment properties

With organic amendment properties, the potential of digestates to improve the physical characteristics of soils are assessed (Beggio et al. 2019). This is estimated using values of pH, total solids (TS), volatile solids (VS) and total carbon (TC). These are the declaration parameters used to assess the digestate quality when it is used for agricultural applications (Peng & Pivato 2019).

The pH of biowaste digestate in Tampere region is 7.7. This is a fairly common value found also in the literature. As appendix 2 shows, the pH values vary between 6.4 and 8.8. Digestates produced from OFMSW can reach pH values over 8. PH above 7 suggests, that alkaline digestate can be useful from the soil acidification point of view. Alkalinity can also enhance the immobility of potential heavy metals in remediation of contaminated land (Peng & Pivato 2019). The pH increases due to the degradation of more than 90 % of volatile fatty acids. Higher pH causes an increased risk for NH_3 volatilisation (Vaneeckhaute et al. 2017).

During anaerobic digestion, easily degradable organic matter is converted into methane (CH_4) and carbon dioxide (CO_2), while complex organic matter remains in the digestate, increasing its amount of effective organic carbon. (Vaneeckhaute et al. 2017) When OFMSW is treated in dry digestion process, digestate of nearly 35 % solids content is produced. Total solids content of the whole digestate from OFMSW vary from 0.72 to 51.2 %, while with digestate from food waste it remains under 10 % (Peng & Pivato 2019). The variation is big also in statistical analysis of OFMSW by Beggio et al. (2019), as shown in Appendix 2.

Volatile solids content is relatively high for both types of OFMSW and food waste digestate, which shows that high amounts of organic matter of the feedstock remain undigested. High organic matter content (60-80 % TS) especially in solid fraction of food waste digestate can help to enhance soil physical properties (Peng & Pivato 2019).

In the study of Vaneeckhaute et al. (2017), the organic dry matter varied between 30-80 %, with higher values for increasing fractions of kitchen and garden waste. The average dry matter content of all kitchen and garden waste was estimated at 21 %, whereas the median of the 213 samples amounted to 8.7 %. (Vaneeckhaute et al. 2017) Higher performance in organic matter degradation could be reached by modifying AD plant configuration options (e.g. higher residence time, increased thermic regime) (Beggio et al. 2019).

The liquid fraction is not only high in nutrients under available forms, but has raised interest also because of its carbon content. Tambone et al. (2019) studied the liquid fraction of digestate obtained after solid/liquid separation. They were especially interested in the organic carbon contents and its ability to act also as an organic amendment and not only as nitrogen fertiliser. The results of the study indicate, that TOC contents were quite high when referred to the dry matter, and were comparable to other typical organic amendments, cattle manure (463 g/kg DM) and compost (247 g/kg DM). The C/N ratio was low and nutrient content high, which is typical of digestates because $N\text{-}NH_{4+}$ flows to liquid fraction during the mechanical separation treatment. (Tambone et al. 2019)

4.5.2 Fertilising properties

With fertilising properties, the micro and macro nutrient content is assessed to evaluate the digestate’s potential to improve soil fertility and crop yield (Beggio et al. 2019). The fertilising properties are estimated using ammonium, total nitrogen, total phosphorus and total potassium content, and conductivity (Peng & Pivato 2019).

If a solid-liquid separation of the digestate is done, the nutrients are distributed between the solid and liquid fraction. Liquid digestate is estimated to contain 70-80 % of the total $NH_{4+}\text{-}N$ while the remaining 20-30 % is distributed in solid fraction. 55-65 % of the total phosphorus remains in solid fraction and the remaining 35-45 % in the liquid fraction. The P_2O_5/K_2O ratio of whole digestate from food waste is around 1:3, being ideal for e.g. grain and suitable supplement of phosphorus and potassium in soils (Peng & Pivato 2019).

The nitrogen content in the digestate of Nokia biogas plant is calculated to be 7.84 kg/t in liquid digestate and 5.67 kg/t in composted dry digestate. (EcoProtech 2019) The results of statistical analysis show big variation, as can be seen in Appendix 2. Beggio et al. (2019) agree with Lakehurst (2010) with total nitrogen content alone being unable to estimate the fertilisation potential of digestate. In digestion process, the organically bound nitrogen is released as ammonium (NH_{4+}), which is directly available for crop uptake. The higher the share of NH_4-N, the higher the efficiency of the digestate is as nitrogen fertiliser. The ammonia content of the digestate accounts for 60-80 % of its total nitrogen content, but those with kitchen and garden waste origin don’t often reach over 50 % share (Vaneeckhaute et al. 2017).

Soil microbes need 25-fold amount of carbon compared to nitrogen. If the carbon-nitrogen ratio is much higher, nitrogen is bonded into soil and released for vegetation later. Soluble nitrogen effects only on the year of spreading, whereas nitrogen tied in organic matter is released slower. (Tampio et al. 2018)

The total phosphorus content of the input streams is not changed during the digestion process, but the organically bound phosphorus becomes available for the plant during digestion (Vaneeckhaute et al. 2017). The phosphorus content in the digestate of Nokia biogas plant is calculated to be 0.89 kg/t in liquid digestate and 3.97 kg/t in composted dry digestate. (EcoProtech 2019) The share of phosphorus in solid digestate in Nokia is bigger than estimated by Peng & Pivato (2019), but solid digestate cannot be compared straightforward with composted digestate.

Comparison with the results of other studies in Appendix 2 show, that phosphorus content can vary between 2.8 and 15.3 g/kg TS. The P_2O_5 content of whole digestate from OFMSW and food waste is quite similar, but with food waste, difference in phosphorus content between solid and liquid digestate is larger.

The potassium content in the digestate of Nokia biogas plant is calculated to be 2.95 kg/t in liquid digestate and 2.85 kg/t in composted dry digestate (EcoProtech 2019). Compared with the range suggested by Target Renewables (2019), the potassium content in both digestates in Nokia seems very low. The results of other studies presented in Appendix 2 show, that with food waste, potassium seems to be devided quite equally between solid and liquid digestate. Yet, potassium is water soluble, and in solid-liquid separation it normally concentrates in liquid fraction, as the results with OFMSW confirm (Tampio et al. 2018).

Electrical conductivity of unprocessed digestate set between 20 and 45 mS/cm in the study of Vaneeckhaute et al. (2017). Appendix 2 shows the values of OFMSW and ready compost and liquid fertiliser were lower, 1.0-11.7 mS/cm. Conductivity of the biowaste digestate in the new plant is estimated to 152 mS/m. Excess salinity has been found harmful both for crop growth and terrestrial organisms. For these reasons, conductivity of digestate is usually measured and declared even if no maximum requirements are set by regulations or certification schemes (Beggio et al. 2019).

4.5.3 Environmental impact properties

Digestate properties with environmental impacts include biological stability, physical and chemical contaminant concentrations and pathogen presence. These are used to assess the potential risks of digestates on ecosystems (Beggio et al. 2019).

According to Peng & Pivato (2019), the concentration of organic acids, volatile fatty acids and the residual biogas potential (RBP) of the digestate can be used as indicators of the degree of fermentation, which is a measure of stability of the digestate. Biological stability is an important indicator for the utilisation of digestate, because unstable digestates can produce high level of leachate and odors. (Peng & Pivato 2019) In the new EU Decree on CE certified fertilisers, the biological stability should be assessed according to residual methane potential (RMP) and oxygen uptake rate (OUR). (EC 2019/1009) The oxygen uptake rate represents the aerobic stability indicator while residual methane potential represents the anaerobic stability of the digestate (Peng & Pivato 2019).

Results of stability indicators from different datasets are presented in Appendix 2. Residual methane potential can vary in the range of 77 - 399 litres biogas/kg VS, the mean being 278. The RBP of liquid digestate seem to have bigger variation than that of solid digestate. Comparing volatile fatty acids again show a big variation. Oxygen uptake rate seems to be higher with digestates from OF-MSW than of food waste. As majority of the organic matter remains in the solid fraction of digestate, it might be less stable than the liquid and whole digestate (Peng & Pivato 2019). The solid digestate might need further stabilisation to meet the required limits (Peng & Pivato 2019).

Physical contaminants are considered to be all the non- or low-digestible materials e.g. plastic, glass, metal scrap, stones, sand and wood. These can be found in all types of feedstock, but mostly in household wastes, food waste, garden waste, straw, solid manure and other solid waste. The impurities can cause negative public perception of digestate and increase the operational costs of the biogas plant by causing wear and tear to plant components and the digestate application machines. Sand can also accumulate in the digester and reduce its active volume (Lukehurst 2010).

The control and management of physical impurities means mainly ensuring high purity feedstock. This can be done either by sorting at source or by on-site separation. Additional safety measures like sieves and stone traps can be installed in the pre-storage tanks. (Lukehurst 2010)

Not much data is available on amounts of physical contaminants in digestate. A new concern is microplastics, which are less than 5 mm diameter plastic particles formed with plastic product embrittlement, synthetic textile fibres and road traffic. Microplastics contain additives such as softeners and surfactants, which might pose a risk to the environment. This challenge is more related to sewage sludge than biowaste based digestates (Tampio et al. 2018).

Also chemical contamination of digestate usually comes from human sources such as sewage and includes inorganic materials (e.g. heavy metals) and persistent organic compounds. Agricultural by-products can contain small quantities of antibiotics, disinfectants and ammonium (Lukehurst 2010). Partly for these reasons, in Nokia biogas plant sewage sludge and manure will be processed separately from biowaste, in a wet digestion line. In the study of Longhurst et al. (2019), feedstocks derived from human food waste and processed by composting and anaerobic digestion were expected to contain negligible chemical contamination (Longhurst et al. 2019).

The heavy metal content of the Nokia plant feedstock and digestate were not measured except for copper and zinc. Cu and Zn fit in the range observed by Beggio et al (2019) in Appendix 2, but are still higher than other values found in literature. Comparing whole digestate from OFMSW and food waste, Peng and Pivato (2019) found higher concentrations for OFMSW with nickel and chromium. In other sources, the mean values of Ni and Cr along with other metals were in the same range with food waste digestate.

The total contents of K, Ca, Mg and heavy metals are not altered during anaerobic digestion, but they become soluble. Zinc and copper contents in the digestate can become critically high especially with pig slurry (Vaneeckhaute et al. 2017). Comparing heavy metal content of the digestate from food waste with the compliance criteria, Peng and Pivato (2019) observed that all the heavy metals were below regulatory limits, and therefore could suggest that digestate from food waste has little risk in agricultural use. Also in the study of Beggio et al. (2019), heavy metals from both OFMSW and AGRO (agro-industrial feedstocks) datasets did not exceed legal threshold requirements. The OFMSW dataset shows mean concentrations higher than the AGRO dataset for Cd, Pb, Hg and Ni (Beggio et al. 2019).

The presence of biological contaminants in digestate, such as various pathogens, prions, seeds and propagules, may result in new routes of disease transmission between animals, humans and the environment. For agricultural use, the product needs to have limited pathogens, viruses and weed seeds. Therefore, strict control of specific feedstock types and of digestate is required. The risk of sanitary issues is mainly related with manure and sewage sludge (Lukehurst 2010; Vaneeckhaute et al. 2017; Beggio et al. 2019).

Weed seeds and pathogens can be killed off during the digestion process. The digester temperature alone is not able to reduce the pathogens. The combination of the conditions in the digester - pH level, quantities of volatile fatty acids, the negative effect of ammonium and hydrogen sulfide - together with time and temperature, combine to create the hostile environment for the spores. Since the conditions inside the digester can vary between digesters and between feedstock, one needs to be careful in making generalisations. (Lukehurst 2010)

In sanitary issues related to digestate land application, Salmonella and Coliform bacteria are measured. Specific attention is also required, when animal by-products are used as feedstock for anaerobic digestion. The control of biological contamination includes for example ensuring the health of the livestock, excluding hazardous biomass types and heating the feedstock at high (70°C) temperature. Nokia biogas plant will not accept or handle animal by-products, and manure is processed in a separate line. In general, there is still lack of data on hygienic issues, microbiological features, ecotoxicological assessment and physical impurities (Lukehurst 2010; Beggio et al. 2019).

4.6 Digestate as fertiliser product

Digestate can be land applied once they meet relevant regulatory standards and can be qualified as a “product”. Some European countries have their own digestate quality standards. They have specifications for hygienic standards, impurities, degree of fermentation, odor, organic matter content and heavy metal content. The parameters for declaration outline the essential characteristics and constituents of digestate products, which help the end user to evaluate its land application. (Peng & Pivato 2019)

In general, the fertiliser products need to be homogenous, safe and suitable for their purpose. The raw materials need to be safe and comply with set regulations. More specific regulations on the quality, handling, use, transportation and storage requirements of fertiliser products and their raw materials are given in Decrees. (Laki 539/2006)

The producer of fertiliser products can decide whether to follow the national regulations or EU regulations on fertiliser products. Only fertiliser products listed in the national type designation list of fertiliser products or products with the new CE-label can be produced or imported to markets in Finland. (Laki 539/2006; Ruokavirasto 2019)

4.6.1 Finnish product requirements for fertiliser products

In Finland the recycled fertiliser products are categorised in type names and type designation list according to their composition and production method (Tampio et al 2018). The type designation groups for fertiliser products are fertilisers, liming materials, soil conditioners, substrates and microbe products (Laki 539/2006; Ruokavirasto 2019).

When the right category of fertiliser product is found, information needs to be provided also about the raw materials, production process, physical features, fertiliser effects, chemical and biological composition, the behaviour in the soil, storage requirements and instructions for use. All fertiliser products put on the markets need to have a product label. That should include name and type of the fertiliser product, and information about the features, composition, use and the producer. The Decree of the Ministry of Agriculture and Forestry set more specific requirements on the product labels (Laki 539/2006; Tampio et al. 2018).

The Finnish quality criteria for fertiliser products are listed in Decree 24/11 and shown in table 9 together with European criteria and limits set for organic farming. The producer has a so called severe responsibility on meeting the requirements of the product. Products intended for occupational use need to comply with the regulations, or the possible harm caused and the loss of income needs to be compensated. (Tampio et al. 2018)

TABLE 9. Quality criteria for fertiliser products (889/2008; 24/11; 2019/1009)

Parameter	**Unit**	**2019/1009 solid organic fertiliser**	**2019/1009 liquid organic fertiliser**	**2019/1009 soil improver**	**889/2008**	**24/11**
Dry matter content	%			>20		>20 ***
single nutrient (N or P_2O_5 or K_2O)	mass %	>2.5 / >2 / > 2	>2 / >1 / >2			1 / 1 / 1
multi nutrient (N + P_2O_5 + K_2O)	mass %	1 + 1 + 1	1 + 1 + 1			1 + 1 + 1 **
with total nutrient content	mass %	>4	>3			>3
C_{org}	mass %	>15	>5	>7.5		
heavy metals (max)						
As	mg/kg DM	40	40	40		25
Hg	mg/kg DM	1.0	1.0	1.0	0.4	1.0
Cd	mg/kg DM	1.5	1.5	2.0	0.7	1.5 *
Cr	mg/kg DM	2.0 *Cr_6	2.0 *Cr_6	2.0 *Cr_6	0 *Cr_6 / 70 Cr_{tot}	300
Cu	mg/kg DM	300	300	300	70	600
Pb	mg/kg DM	120	120	120	45	100
Ni	mg/kg DM	50	50	50	25	100
Zn	mg/kg DM	800	800	800	200	1500
Se	mg/kg DM					20
Salmonella	number/25 g sample	0	0	0		0
Escherichia coli	pmy/g	<1000	<1000	<1000		<1000
physical impurities (glass, metal, plastics)	% of FW					0.2 - 0.5
physical impurities (glass, metal, plastics)	g/kg >2mm	<3	<3			
sum of impurities	g/kg	<5	<5			
PAH_{16}	mg/kg DM	<6	<6			
OUR	mmol O_2/kg OM/h	<25	<25			
RBP	litre biogas/g VS	<0.25 (CMC5)	<0.25 (CMC5)			
self-heating factor	Rottegrad	III (CMC3)				

* for fertiliser products with >2.2 % P (5% P_2O_5), the maximum for Cd is 50 mg/kg P (22 mg/kg P_2O_5)

** in liquid fertiliser products

*** for soil improver

Comparing digestates analysed in Tampere region (Mönkäre 2018a) with the quality criteria in table 9 confirm, that digestates suit in traditional agricultural use as organic fertilisers and soil improvers. In organic farming Cu and Zn of digestate could raise concern, but solid-liquid separation and composting will reduce the concentrations.

4.6.2 EU product requirements for fertiliser products

EU Decree 2019/1009 on fertiliser products list product requirements for EU fertiliser products. They must

1. meet the requirements for the relevant Product Function Category;
2. meet the requirements for the relevant Component Material Category or categories; and
3. be labelled in accordance with the labelling requirements. (EU Decree 2019/1009).

In the new Decree, suitable Product Function Categories (PFCs) for digestates could be organic fertiliser (solid or liquid), organic soil improver and mechanical blend of fertiliser products. Organic fertilisers provide nutrients to plants or mushrooms. They can contain organic carbon (C_{org}) and nutrients of solely biological origin, and they should contain at least one of the following declared primary nutrients: nitrogen (N), phosphorus pentoxide (P_2O_5) or potassium oxide (K_2O) (EU Decree 2019/1009). Minimum nutrient contents for solid and liquid organic fertilisers are presented in table 9. Organic fertilisers should have organic carbon at least 15 % by mass for a solid and 5 % by mass for liquid form.

Table 9 shows the EU limit values for contaminants are close to national limits. In case of As and Pb, Finland has more strict limits than EU, whereas with Cu, Ni and Zn Finland allows higher concentrations than the new EU decree. The new decree sets also limits for pathogens, PAH16 and physical impurities in organic fertilisers.

Soil improvers, the other suitable PFC, are intended to maintain, improve or protect the physical or chemical properties, the structure or the biological activity of the soil. They should consist of material 95 % of which is of solely biological origin. (EU Decree 2019/1009) As seen in table 9, the limits for contaminants and pathogens are the same as with organic fertilisers, with the exception of higher (2.0 mg/kg dry matter) limit for cadmium.

Component Material Categories (CMCs) listed in Annex II of (EU) 2019/1009 define the component materials, which an EU fertiliser product can consist of.

For the Nokia biogas plant, suitable CMCs are Compost (CMC 3) and Digestate other than fresh crop digestate (CMC 5) (EU Decree 2019/1009). The quality criteria for compost and digestate are listed in table 9, which shows that the limit values are the same for both. With stability, for compost either oxygen uptake rate (OUR) or self-heating factor is used, whereas for both solid and liquid digestate either OUR or residual biogas potential (RBP) is used.

Compost (CMC 3) may contain compost obtained through aerobic composting of biowaste resulting from separate biowaste collection at source; also when it has previously been digested. Composting additives, which are necessary to improve the process performance or the environmental performance of the composting process, are approved, but their total concentration cannot exceed 5 % of the total input material weight. Composting has to take place in a plant in which production lines for the processing of input materials are clearly separated from materials of different production lines, and where physical contacts between input and output materials are avoided, including during storage. (EU Decree 2019/1009)

CMC 5 is the other suitable Component Material Category. This category allows biowaste from separate biowaste collection at source as input material, but not the organic fraction of mixed municipal household waste separated through mechanical, physiochemical, biological and/or manual treatment or sewage sludge or industrial sludge. For CMC 5, the same limitations with production lines and storage of materials apply as with CMC 3. (EU Decree 2019/1009)

During the digestion process, all parts of each batch need to have a temperature-time profile of either thermophilic anaerobic digestion at 55 °C for at least 24 hours followed by a hydraulic retention time of at least 20 days; or thermophilic anaerobic digestion at 55 °C followed by composting in

- 70 °C or more for at least 3 days,
- 65 °C or more for at least 5 days,
- 60 °C or more for at least 7 days, or
- 55 °C or more for at least 14 days. (EU Decree 2019/1009)

The following information has to be provided with EU fertiliser products:

- Product Function Category
- the quantity (mass or volume)
- instructions for use, including application rates, timing and frequency, and target plants
- recommended storage conditions
- any relevant information on risk management; and
- list of all ingredients above 5 % by product weight.

In addition, product-specific labelling requirements are given in Annex III of the Decree. (EU Decree 2019/1009)

4.6.3 Organic farming and other uses

There is no separate acceptance system for fertiliser products used in organic farming. The additional fertilisers permitted in organic production are listed in EC Decree 889/2008 Annex I. When the product complies also with the regulations on fertiliser products, it can be used in organic production. The Finnish Food Authority keeps a list of fertiliser products suitable for organic farming. The suitability is estimated based on product composition, not the effectivity. (Ruokavirasto 2020) As table 9 shows, limit values of heavy metals in fertiliser products used in organic farming are much stricter than European and Finnish ones.

Different countries can have their own limit values. For example in Austria, where anaerobic digestion of biowaste is common, also limit values for different organics (e.g. dioxins, furans and AOX) are set (Peng & Pivato 2019). Some businesses have also given their own recommendations for nutrient values. For example, the green construction business aims at using fertilisers only based on plant requirements. The quality and environmental program of the industry prefer slow nutrient release and prevention of nutrient leaching. Also the Finnish Association of Landscape Industries has published recommendations for nutrient contents of substrates (Tampio et al. 2018).

4.7 Product quality management

Decree 24/11 lists the national quality requirements for fertiliser products, including maximum concentration for harmful substances, pathogens and impurities in fertiliser products. Products destined to European markets or marked with CE-label need to comply with the European regulation, and producers targeting to organic farming markets have to be even more careful with the raw materials and heavy metal concentrations of their products.

Production of good quality digestate for use as biofertiliser is the result of careful control of all aspects of the process, from feedstock to field. Feedstock selection, complying with strict standards (government and/or farmer determined) and compliance with codes of good agricultural practice are all key issues in quality management (Lukehurst 2010). For organic fertiliser products to become competitive with traditional fertilisers also in terms of processing and costs, the variation in quality must be reduced (Seppänen et al. 2018).

Several European countries have created standards for digestates defining the limits of specific parameters in agricultural applications. Foreign quality management systems may give certificates to products, processes or production units. (Tampio et al. 2018; Peng & Pivato 2019)

4.7.1 Risk estimates

Harmful substances in biowaste, their risks and reduction in processing have been studied also in Finland. The conclusion has been that the use of organic fertiliser products causes no danger to people. In some cases zinc and cadmium has been found to affect the earth microbes or ground waters, but it mostly concerns sludges. Organic fertiliser products based on biowaste don't usually contain medicines, when the waste separation is working. (Mönkäre et al. 2016)

Risks have been estimated also in the study of Longhurst et al. (2019), using plausible worst case assumptions. Their conclusion was that quality-assured, source-segregated products applied to land, under quality protocols and waste processing standards, pose negligible risk to human, animal, environmental and crop receptors, providing that risk management controls set within the standards and protocols are followed (Longhurst et al. 2019).

Most organic harmful substances originate from sewage sludge. BIOSAFE-project executed in the beginning of 2010's found, that the amount of harmful substances coming with fertiliser products equals the amount of atmospheric fallout. Sewage sludge, manure and grease sludge can also bring problematic concentrations of drugs and hormones in digestates (Tampio et al. 2018). In the Nokia plant, these waste types are digested separately apart from dry digestion of biowaste to reduce risks in the digestate.

4.7.2 Quality management systems

In addition to legislation regulating production of fertiliser products, voluntary quality management systems can be used to assure quality production and products. An interview was conducted with Finnish producers (current and potential) of fertiliser products in November 2019 by Visia. The aim of the survey was to find out the producers' opinion on quality issues and the changes in the production environment. Most companies interviewed considered legislation as the most important quality management tool. Especially requirements of facility approval and own-check systems help to control the production quality. Environmental management systems (ISO 14001) and Quality management systems (ISO 9001) are in use with many companies, also Health and safety management system (ISO 45 001) and OHSAS 18 001 were mentioned. Product quality management is not so often used, but the following programs were mentioned: Fertilizer Europe's Product stewardship principles, Responsible care Product liability program and the new national LARA quality assurance system (Osuuskunta Visia 2019).

4.7.3 Lara quality assurance system

A new national quality management handbook for Finnish fertiliser products was published in spring 2019. The quality management system has been built during the past three years as part of Lara Laaturavinne -project, financed by the Finnish Ministry of the Environment. The quality management handbook describes how a quality management system and quality label for fertiliser products can be achieved. (Laatukäsikirja 2019)

Lara quality assurance system and Laatulannoite -quality label is a service and a tool for the users of fertiliser products as well as for the producers, advisors, researchers and authorities. The system aims to increase the use of recycled nutrients as well as enhance nutrient recycling. In building the Lara Quality assurance system, the ECN-QAS Quality Manual and the German Qualitätsmanagement Handbuch (QMH) were utilised. (Laatukäsikirja 2019)

The products Lara quality assurance system (QAS) can be used with are
1. Compost
2. Digestate (solid or liquid)
3. Dry/solid digestate (dry matter content min. 15 %)
4. Reject water (dry matter content max. 15 %)
5. Concentrated liquid fertiliser product
(Laatukäsikirja 2019).

The main point of Lara quality management system is the quality of the end product. Besides quality assurance, also traceability of the raw materials and transparency of the material chain is important. Facilities approved by the Finnish Food Authority already have a plan for ensuring the traceability of raw materials. Requirements related to this own-check system and plant specific environmental permit are monitored in auditing of Lara QAS. (Laatukäsikirja 2019)

4.8 Markets

Different ways of organizing marketing and distribution of digestates are used. The biogas plant can sell the fertiliser products from the plant, deliver them to the field or use a third party to take care of storage, marketing and/or distribution. Farmers may also be interested in more refined products. (Mönkäre et al. 2016) The expectations of the producers and end users of fertiliser products have been studied for example in BioRaEE-project and EIP-Agri study. The market possibilities near Nokia biogas plant were investigated in Ravinnevisio-study and a web survey with the farmers in Tampere region.

Finnish Environment Institute and Natural Resources Institute studied the experiences and needs of farmers for fertiliser products in BioRaEE-project. It was found, that over 70 % of farmers considered fertiliser products as good addition to support mineral fertilistation. Organic farmers were more positive towards fertiliser products than traditional farmers, where over 60 % didn't think fertiliser products alone would offer enough nutrition. (Seppänen et al. 2018)

Clear contradictions could be found in the responses of farmers and producers of fertiliser products. The essential challenges are the phase of the product, nutrition balance, storage capability, raw material, price, recognisability and knowledge. Both sides seem to prefer current ways instead of developing processes to improve market situation. (Seppänen et al. 2018)

One of the issues that need most improvement seems to be the storage of products. Both the farmers and the producers would prefer the other partner to take responsibility of the storage. Big biogas facilities usually have good storage readiness, but products need to be transferred to farms well before the spreading season, which means storage solutions are needed also at the farms or in their vicinity. 55 – 65 % of farmers considered storage of products challenging, and most considered storage in large bags as the only storage option. Dry fertiliser products were considered the best also from the application point of view; best suited would be hails or dry products resembling dry manure. All in all, farmers seem reluctant to invest in application equipment and storage of products at farms. This could be solved by using a third party, who takes responsibility of the storage and possibly also application services. It would still mean more interest in agricultural practices and product development is required from the producer side, instead of just technical operation of the plant. (Seppänen et al. 2018)

Another expectation from the markets is well optimised nutrition balance for different plants. Fertiliser products could be mixed with other products to improve the nutrition balance. If the end products don’t offer what is demanded by farmers, there will be no market for products. Nutrition balance brings also challenges to pricing of products; with mineral fertilisers, price is usually based on nutrition content, but recycled fertiliser products have additional useful qualities such as microbes and organic material. In addition to minimum requirements of legislation, commonly agreed quality criteria for fertiliser products could be useful also from pricing point of view (Seppänen et al. 2018; Tampio et al. 2018).

Similar challenges were found in EIP-Agri study, which was made with European farmers and producers of digestates. Marketing of fertiliser products were found challenging due to its varying composition and management styles. Also marketing to the nearby areas was found challenging, and increasing distances increase costs. Both in EU and in Finland, nutrition balances of soils vary with production areas. In the areas of dense animal husbandry, more phosphorus is produced than can be used, and in other areas there is lack of phosphorus. Distances between areas can be big. (Seppänen et al. 2018)

In Tampere region the demand of phosphorus in fields after manure application is still about 1400 tons/year. Digestate from biowaste could cover close to 3 % of all phosphorus demand in Tampere region. For soluble nitrogen the need is over 13 000 tons/year, of which digestates could cover less than 1 %. Looking closer to Nokia biogas plant, the digestates could cover all of phosphorus addition in Nokia. In Ravinnevisio-study it is assumed, that 20-30 km radius from the biogas plant is sufficient to utilise digestates, if farmers are willing to make a contract with the biogas plant. (Mönkäre et al. 2016)

PJH studied the interest of farmers towards organic fertilisers and soil improvers in Tampere region in 2017. A questionnaire was posted to over 3000 farms in

20 municipalities, and the interested parties were contacted by phone. Altogether 65 organic farms were interested in the recycled fertilisers. The price and availability were the key issues. (Pirkanmaan Jätehuolto. 2017)

Seppänen et al (2018) studied the current digestate refinement and its potential in Finland. Digestates are not refined much in Finland, and there were not many recycled fertiliser products in the markets optimised for the needs of the farmers. The study revealed that farmers consider the fertiliser products as a good addition to traditional mineral fertilisers, as a potential path in transferring to organic farming and as good soil improver. The biggest obstacles for the use of fertiliser products were found to be price, nutrition balance, phase, storage requirements and ways of application. Further development is needed for the fertiliser products to suit better for the needs of end users (Seppänen et al. 2018).

In European level, the demand for controlled and slow-release (CSR) fertilisers, such as struvite, is estimated to grow. They have proved to be environmentally friendly, resource-saving and labor-saving, but have still a high price. Coated fertilisers, particularly polymer-coated products, have been the fastest-growing segment of the CSR-fertiliser market. (Vaneeckhaute et al. 2017)

Until recently, refinement of fertiliser products has been part of waste management process. The market value of the products does currently not cover the costs of production. More knowledge and know-how of productisation is needed in the industry. Labelling of recycled nutrients does not guarantee success in the markets, unless the product has a competitive price and even quality and it is easy to use. Finnish safety and quality criteria has to be met, as well as the nutritional requirements of plants. (Tampio et al. 2018)

Also Longhurst et al. (2019) concluded that risk estimates are no guarantee of how risks might be perceived by producers, suppliers or consumers. Further research is needed to identify residual contaminants such as pharmaceutical products residues, persistent organic compounds, antimicrobial resistant pathogens and microplastics in fertiliser products. (Longhurst et al. 2019)

4.9 Future

On average over 80 % of nitrogen and 25-75 % of phosphorus consumed end up lost in the environment, wasting the energy used to prepare them and causing emissions of greenhouse gases and nutrients to water (Vaneeckhaute et al. 2017). The limited resources of phosphorus and natural gas will increase the prices of mineral fertilisers in the future, and the depletion of soil carbon reserves cause problems in world's food production because of erosion. These global trends will increase the importance of recycled fertilisers and their development. (Seppänen et al. 2018)

The role of digestate refinement will increase. Currently the biggest challenges for that are the state of the digestate markets, competition with mineral fertilisers, required investments in new technologies and the resulting challenges in profitability. Producers of fertiliser products also need to know and consider the needs of the customers better. (Seppänen et al. 2018)

Recycled fertilisers need clear solutions for storage and spreading, as well as manual for their use in different circumstances and with different plants. Professionals of marketing fertiliser products are needed, because product development requires knowledge of both plant nutrition and farming practices. Suitability for organic farming needs to be considered, because that is a potential customer group for fertiliser products. (Seppänen et al. 2018)

It is important for the development of the markets to get more information about products characteristics and long-term field trials using digestates. The field trials have focused on plant yield and phosphorus uptake, but more information is needed also on the mobility of other nutrients and heavy metals. Best management practices with optimization of fertiliser use could be developed into a model library. (Vaneeckhaute et al. 2017)

As Vaneeckhaute et al. (2017) have concluded struvite precipitation/ crystallization, NH_3-stripping and adsorption and acidic air scrubbing could be considered as best available technologies for nutrient recovery from digestate. Still, all technologies require further technical fine-tuning in order to minimise operational costs, especially towards energy and chemical use, and to improve the quality and predictability of the produced fertilisers (Vaneeckhaute et al. 2017).

To be successful in marketing fertiliser products, it is wise to plan the products from the start to meet the customer demands. Effort is needed in both in planning, branding and marketing (Tampio et al 2018). Already in planning biogas plant investment, storage and application solutions of digestate should be considered. Co-operation between producers and farmers has to be strengthened, and education for agricultural advisors is needed (Seppänen et al. 2018).

5 CONCLUSIONS

The utilisation of biowaste is inarguably a good solution in biogas production. Also production of recycled fertilisers from resulting digestate is seen as economically and ecologically smart.

European regulations concerning both fertiliser products and organic farming have been renewed recently, and implementation into national legislation is partly under construction. These need to be followed carefully to be aware of the requirements for the digestate utilisation.

Biowaste as feedstock in the AD process is approved and its quality is well known. If any changes to the process feedstock are planned later, the legal requirements have to be re-evaluated. If in the future there would be a waste separation plant, that is capable of separating more biological waste from the mixed waste stream, it is generally advised, that in order to avoid risks the mechanically separated organic waste is not mixed with separately collected biowaste.

The digestates produced in dry digestion of source-separated biowaste can be used as fertilisers or soil improvers in agriculture, also in organic farms. The quality of the digestates can vary a lot, and therefore it has to be re-analysed, once the biogas plant starts operation. The monitoring should be frequent and regular to assure even quality meeting the regulatory demands.

A lot of work is still needed to promote the fertiliser products. Quality protocols for production would be useful to help produce good and even quality fertiliser products. Sharing good practices is often done especially between municipal waste management companies, and that could benefit all producers. As long as the market is local and competition does not affect the situation, sharing good practices could be utilised.

More thought should be given to storage and application procedures. There are already third party operators who can take responsibility of transportation, storage, mixing products, marketing and even application. When a new biogas plant starts operation, it could be a smart solution to outsource the marketing of fertiliser products to a third party. This is especially in early stages of operation, when there can be large variations in product quality.

I would suggest that with the Nokia biogas plant, the company would concentrate on learning to operate the process first, and only later start focusing on fine tuning of the fertiliser products. Especially with the liquid digestate, the process output is new to the operator and the connections to farmers and potential markets are weak. A contract with a third party would most likely be helpful, at least in the beginning, to make sure the storage is handled well and products can be utilised in fertilisation.

With the dry digestate, the operator has more possibilities to work with the existing infrastructure. The company has produced compost for green construction for more than a decade, and has established a good market position. With that experience and existing customers, the dry digestate composting and refinement into soil improver would be relatively easy. Also storage possibilities for compost products at the facility are better than for the liquid digestate.

Regardless of whether the digestate and fertiliser products go to a third party or directly to the customer, the quality issues have to be managed well. Quality assurance has to be regular, systematic and well documented. It can be done with a well prepared own-check system or adopting a quality management system. The new national quality assurance system Lara could be a good option, as it is designed for fertiliser products. As an operator, the company needs to know how to produce good quality digestate and how it can be modified. Good quality improves the situation in the markets and therefore also the profitability of the biogas plant.

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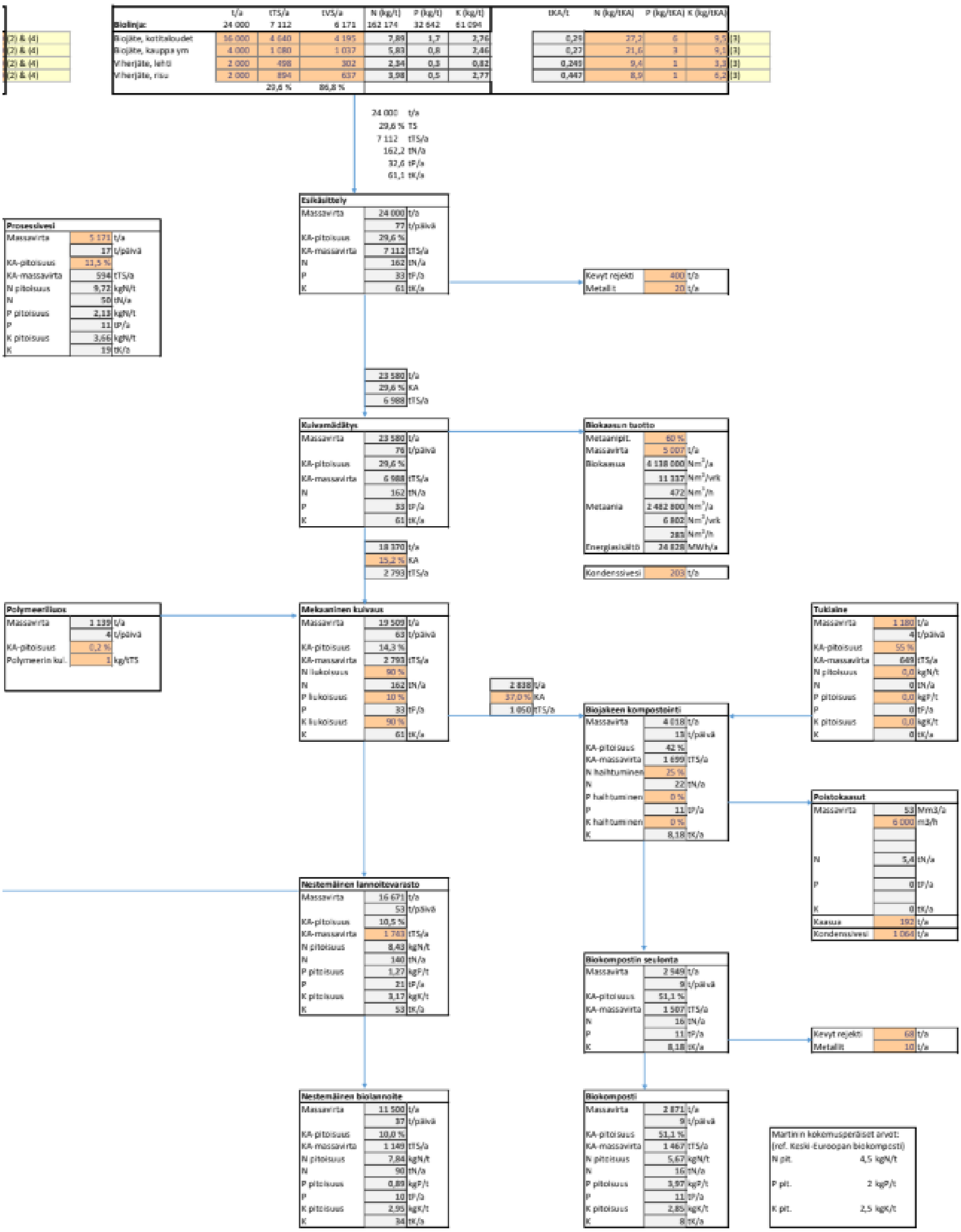
APPENDICES

Appendix 1. Nutrient values in different stages of dry anaerobic digestion of biowaste in Nokia biogas plant (EcoProtech 2019)



Appendix 2. Quality parameters of digestates (Vaneeckhaute et al 2017; Beggio et al. 2019; Peng & Pivato 2019; Target Renewables 2019)

		OFMSW*			food waste*			post-digestion	presswater**	unprocessed digestate***		OFMSW dataset****		
parameter	**unit**	**whole**	**solid**	**liquid**	**whole**	**solid**	**liquid**	**compost**	**liquid fertiliser**	**median**	**unit**	**median**		**variation**
Basic characteristics														
pH		8.30	8.80	8.34-8.80	7.60-8.30	7.97	7.9	7.6 - 7.7	7.5 - 8.5	8.3		7.69		6.4-8.3
organic matter	w%									5.3				
total solids	%	0.72-51.2	7.23-27.0	3.90	1.99-7.88	9.00	3.23	34 - 58 (% DS)	7.4 - 17.7 (% DS)			87.9	gTS/kgFM	24-311
volatile solids	%TS	62.1	68.0-71.0	66.4	61.7-73.6	80.4	68.4					650.1	g/kgTS	420-738
total carbon	%TS	34.6	12.8-22.7	36.9	32.8-39.5	-	-					357.8	g/kgTS	230-397
electrical conductivity	mS/cm							2.5	1.6 - 2.2	32		6.54		1.00-11.70
Nutrients contents														
N-NH3	g/l	1.7-27.5	-	3.84	3.37	5.7	2.7							
N-NH4	g/l									2.15		81.9	g/kgTS	40.4-99.4
TKN	%TS	2.79-14	-	-	15.4	-	-							
C:N		1.3-29.8	12.1-20.9	2.7	2.63	-	-			6.58				
total nitrogen	%TS	1.3-12.4	1.09	13.85	4.15	3.97	8.65	8.7 - 16.7 (kg/t)	31.3 - 48.8 (kg/t)	0.42	%w FM	109.7	g/kgTS	11.0-121.5
P_2O_5	%TS	0.2-0.9	1.49	1.22	0.93	0.9	2.10	5.1 - 12.3 (kg/t)	11.7 - 19.1 (kg/t)	0.39	%w FM	7.2	g/kgTS total P	2.8-15.3
K_2O	%TS	0.6-1.0	0.78	3.64	2.33	2.33	2.53	7.2 - 21.1 (kg/t)	25.4 - 56.5 (kg/t)	0.35	%w FM	36.0	g/kgTS total K	9.7-59.0
Biological stability														
TOC		27.5-45.9 (%TS)	52.9 (%VS)	-	34.6 (%TS)	-	529.5-570.9 (mg/l)							
COD	g/g VS	1.62	-	-	1.50	1.90	29-50 (g/l)							
VFA	g/kg FM	0.3	-	-	0.18	-	-					6991	mg/l	311-15148
OUR	gO2/kg VS/h	2.82-3.78	-	-	0.68-0.91	-	-							
RBP	l/g VS	0.346	-	-	0.061-0.311	0.185-0.418	0.062-0.410					278	l/kg VS BMP	77-399
Heavy metals														
Cd	mg/kg	0	-	-	<0.4	-	-	0.1 - 0.2 (g/t)	0.34 - 0.50 (g/t)			0.58		0.14-1.58
Pb	mg/kg	15	-	-	9.8-36	-	-	12.6 - 36.4 (g/t)	23.4 - 42.8. (g/t)			18.6		2.00-123.6
Cu	mg/kg	55	-	-	14-80	-	-	22.4 - 66.9 (g/t)	53.6 - 64.4 (g/t)			53.2		19.40-111.00
Hg	mg/kg	-	-	-	<0.23	-	-	0	< 0.1 (g/t)			0.08		0.03-0.10
Ni	mg/kg	50	-	-	11-20	-	-	6.6 - 13.5 (g/t)	11.4 - 23.2 (g/t)			11.03		4.90-24.50
Zn	mg/kg	78	-	-	56-300	-	-	42.4 - 102.8 (g/t)	142.6 - 215.8 (g/t)			233.00		87.4-427
Cr	mg/kg	188	-	-	6-40	-	-	-	33 (g/t)			12.74		6.81-26.60

* Vaneeckhaute et al 2017
** Target Renewables 2019 (units per DS content)
*** Peng&Pivato 2019
**** Beggio et al 2019