Possible Uses for Sludge Digestate in Agriculture: Recommendations for Stormossen Oy’s plant in Vaasa, Finland

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Degree Thesis

Thesis for Energy Technology – NOVIA, University of Applied Sciences

Degree Programme

Vaasa, 2023

DEGREE THESIS

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Specialisation: Energy Technology
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Title: Possible Uses for Sludge Digestate in Agriculture: Recommendations for Stormossen Oy's plant in Vaasa, Finland

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Date: 20.09.2023 Number of pages: 34 Appendices: 1

Abstract

Recent studies show that municipal solid waste production is projected to be at a global rate of 2 billion tonnes per year, where up to 37% of this waste will be dumped in landfills (The World Bank, 2023). Using the biochemical anaerobic digestion process, Stormossen Oy is a Finnish waste management company that primarily treats biowaste and sewage sludge to produce biogas and digestate (Stormossen Oy, 2020). Whilst most of their outcomes are monetised, the sludge digestate is currently considered as waste.

Through a thorough review of literature and European laws, the thesis aims to determine if sludge digestate can be treated as fertiliser. The final purpose was to assess Stormossen Oy on how they could implement a beneficial sludge digestate treatment. Therefore, the sludge digestate compounds information was provided by the company.

According to Regulation (EU) 2019/1009 of the characteristics of an EU fertilising product must-have, the digestate from sewage sludge cannot be used as fertiliser. However, sewage sludge can be used to obtain phosphate salts and their derivates, which can be used in fertiliser manufacturing.

Future studies might be conducted to look at the financial and environmental advantages of processing sewage sludge to produce precipitated phosphate salts and their derivates. Additionally, a more thorough review of legislation could determine if cooking oil could be used during the procedure. Also, a further scenario to be studied could be to pre-treat the sewage sludge to produce precipitate phosphate salts, followed by an anaerobic digestion process to produce biogas.

Language: English
Key Words: sewage sludge, digestate, anaerobic digestion, agriculture, fertilisers

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1 Introduction

Globally it has been estimated that 2 billion tonnes of municipal solid waste (MSW) are produced every year (The World Bank, 2023). Although some of this waste is treated, studies show that up to 37% will be thrown into landfills (Blue Planet, 2022). Therefore, the insufficient control of the natural processes the waste endures after dumping it contributes to generating more pollution.

As the Organisation for Economic Co-operation and Development (OECD) (2015) defines, municipal solid waste (MSW) is the type of waste that is managed either by or for each municipality. More specifically, waste obtained at home, in commerce and industries similar to the domestic and the residues from street cleaning and gardening. This means non-hazardous day-to-day waste: plastic, paper, packaging, glass, food scraps, etc. (Evreka, 2021).

Even if part of it is treated, some of these methods can also produce other residues that could contaminate the environment, which are mainly the ones that turn this waste into energy. According to Student Energy (2021), the expression Waste-to-Energy (WtE) is used to name all the methods used to transform waste that cannot be recycled and would end up in a landfill into energy, either as electricity, fuels, or heat. To do so, the main technologies used are thermal, thermo-chemical, and biochemical (Korneti, 2021). Whilst both thermal (combustion) and thermo-chemical (gasification, pyrolysis, etc.) processes use high temperatures to obtain energy and reduce the volume of non-recyclable waste, the second one is usually more efficient. Whereas the biochemical process, usually anaerobic digestion, uses microorganisms to obtain biogas from waste with organic matter (Ross, 2022).

As explained by US EPA (2019a), the Waste-to-Energy combustion treatment process's main objective is to reduce the waste volume and obtain energy. Although there are new residues obtained from it. Those residues are mainly ashes and what are called flue gases. These must be taken care of in specific ways so that they will not contaminate the environment in other ways.

The thermo-chemical WtE processes differ from the thermal processes mainly in the conditions the thermic degradation of the waste takes place. Due to this difference, the

residues obtained are not only solids (ashes) and gases (flue gases) but also liquids. Depending on the final purpose, the treatments they will have to go through vary (CalRecycle, 2014).

The third type of Waste-to-Energy process, called biochemical, mainly consists of anaerobic digestion of waste that contains organic matter, although it can also be an anaerobic fermentation (CalRecycle, 2013). As US EPA (2019b) stated, this WtE treatment consists of the degradation of said waste but instead of using thermal methods, microorganisms carry out the process. The main products obtained are biogas and digestate (a mixture of solids and liquids) and as the products from the other WtE processes, they have to be treated to not be harmful to the environment. Also, this treatment varies depending on their final use.

Stormossen Oy (https://www.stormossen.fi/en/) is a Finnish waste management company that uses the biochemical method of Waste-to-Energy, more specifically anaerobic digestion, to treat mainly biowaste and sewage sludge to obtain biogas as the main product and digestate.

Currently, the biogas produced is used for three different uses. Those are heat generation for the anaerobic digestion itself, electricity production, and fuel for municipal buses and private vehicles (Stormossen Oy, 2020).

Since the company treats the sludge and the biowaste in different reactors, the digestate obtained can be considered two different types. As can be seen below in Figure 1, the digestate that comes from treating the biowaste (Process 1 in Figure 1) is used as compost soil due to the waste being from households and therefore it does not contain any harmful components. Whereas the sludge digestate (Process 2 in Figure 1), given it is from sewage sludge and used cooking oil, is not used because the components it may contain can cause environmental problems (Thode Filho et al., 2017). In consequence, an enhancement of the treatment of those residues can potentially improve the impact that Stormossen and similar companies have on the environment and could also provide economic benefits.

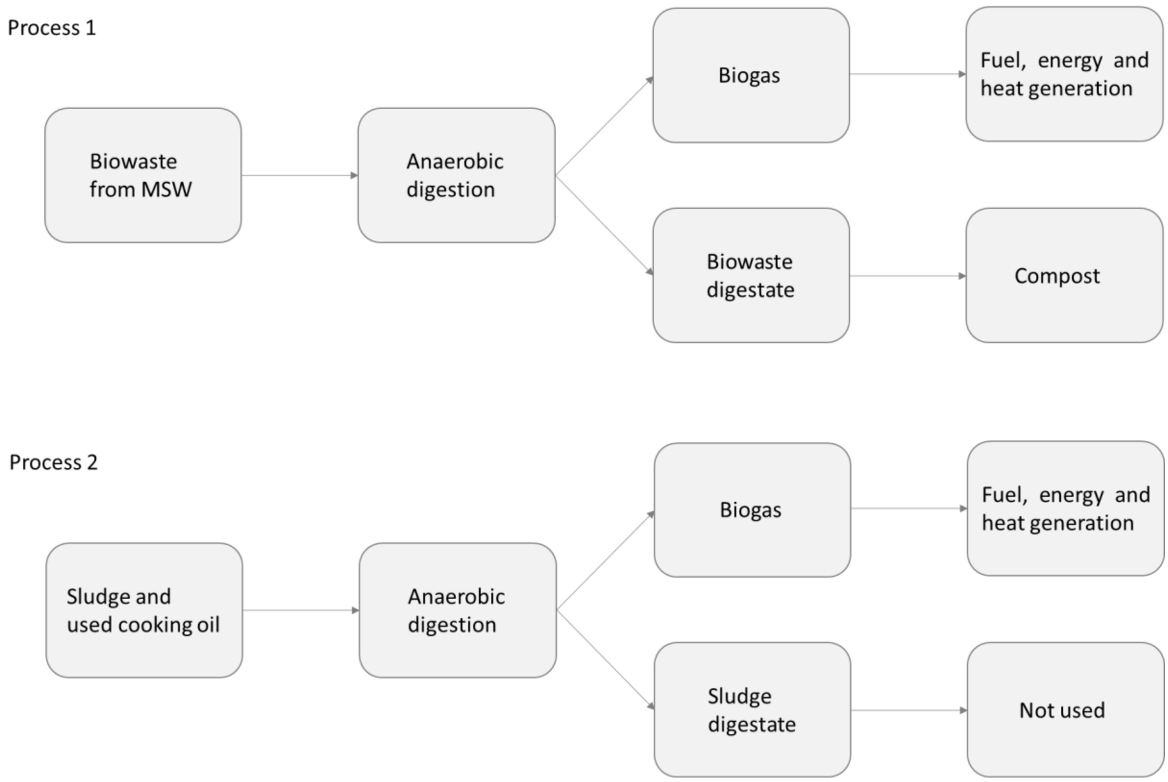

Figure 1. Stormossen Oy's simplified WtE processes for the residues treated (Source: Author's own)

As can be seen above in Figure 1, from both processes Stormossen Oy manufactures, only one end-product is not used, and therefore monetised. Said by-product is the sludge digestate. For this reason, this study will focus on the sludge digestate and which uses it can have in agriculture.

1.1 Aims and objectives

This thesis aims to determine if the digestate obtained by Stormossen Oy from the sludge treatment could be given a purpose in agriculture instead of being discarded as waste. To achieve the aim, the following objectives are defined:

- Identify the end-products present in Stormossen Oy's sludge digestate,
- Review the European Union legislation on possible uses for the digestate from sludge treatment in agriculture,
- Investigate what other EU countries are doing with sludge digestate obtained from similar processes in agriculture, and

- Make recommendations for Stormossen Oy about what can they do with the sludge digestate in agriculture.

1.2 Project purpose

This thesis has been requested by Johan Saarela, the product development manager at Stormossen Oy. Its purpose is to make the circular economy of the company even more circular. It is achieved by treating different waste types (biowaste, sewage sludge, and used cooking oils) and transforming them into different energy types (heat, electricity, and fuel).

Because this business is based on waste treatment, those processes produce byproducts and although some of them can be profitable, there are others (as mentioned before) that cannot be, therefore being new residues.

For this reason, this thesis desires to discuss if it is possible to monetise the sludge digestate in the agricultural area that for the moment are being considered as waste.

1.3 Document structure

This thesis starts by giving an introduction to the actual pace of municipal solid waste produced globally and a brief explanation of the processes it endures when treated to obtain energy from it. After it is explained in short a bit about Stormossen Oy, the company to which this thesis is written. To finish this section (Section 1), the aims, objectives, and the purpose of the thesis are defined.

In Section 2, there is a more detailed explanation about Stormossen Oy followed by a thorough description of the process used to treat the waste.

In the following section, Section 3, the main chemicals analysed by Stormossen Oy from their digestates are briefly described by writing about their nomenclature and since when they have been used, their main uses, and finally their impact on the environment and human health.

Section 4 is used to explain what the European Legislation says about sludge digestate in agriculture and how can it be used and in Section 5 there are examples of what other European countries do with their sludge digestate to be able to use it in agriculture.

Finally, in sections 6 and 7 there is a discussion on the information found and the recommendations made to Stormossen Oy, respectively.

2 Stormossen Oy

Stormossen Oy is a Finnish company based in the Ostrobothnia region with 176,000 inhabitants (Figure 2 locates it on a map). The company is owned by six of its municipalities: Vaasa (68,017 inhabitants), Mustasaari (19,668), Vöyri (6,293), Maalahti (5,483), Isokyrö (4,407) and Korsnäs (2,024) (Stormossen Oy, 2022a).

Figure 2. Ostrobothnia region map (Source: https://www.obotnia.fi/en/).

As stated by Renergi (2017), over the last two decades this organisation has been treating the waste from those municipalities, particularly biowaste and sewage sludge, to obtain both compost soil and biogas. Making it a circular economy business. Both of these obtained products are monetised since they are sold to individuals and public companies.

Biogas is used in vehicles as a substitute for diesel or petrol, where the biogas fuel is not only cheaper than the more common fossil fuels but also the amount of harmful atmospheric emissions are reduced. At the moment, both individuals and public services such as the Vaasa buses can buy the fuel (Stormossen Oy, 2022c).

Based on Stormossen Oy (2022b) the compost soil is the solid product obtained from the biowaste treatment. It is used for gardening as well as for farming. Though logically, it has to be tested to guarantee it is safe and of good quality.

Annually, Stormossen Oy generates about 8,800 tonnes of digestate, which is the solid part obtained from the waste treatment. And about 6,600 tonnes of those are only from the sewage sludge (Figure 3). According to J. Saarela (personal communication, April 2023), approximately 61% of this digestate is mixed with sand and used as soil, which is almost all the digestate from the biowaste treatment and almost half of the digestate from the sludge treatment obtained.

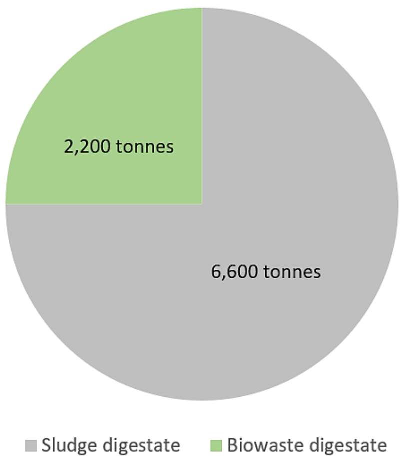

Figure 3. Digestate production in 2022 (Source: Author's own)

This percentage of digestate used can indeed be monetised generating income. However, the digestate generated from the sludge treatment usually is problematic because the raw material used is sludge from wastewater treatment plants, mostly from Påttska in Vaasa, and fats from restaurants and school kitchens.

Although the digestate obtained has different uses depending on which waste source is used, the treatment used is the same for both sources: the anaerobic digestion process (Stormossen Oy, 2022c).

2.1 Anaerobic digestion

Anaerobic digestion, according to Biogen (2021), is a process in which waste containing organic material is broken down in a sealed controlled environment without oxygen to obtain biogas and digestate. This treatment can be considered sustainable since its sources are waste, hence carbon neutral, and the products obtained are used to replace products that come from fossil fuels (Renergon, 2021). The diagram shown in Figure 4 illustrates the main parts of a standard anaerobic digestion process.

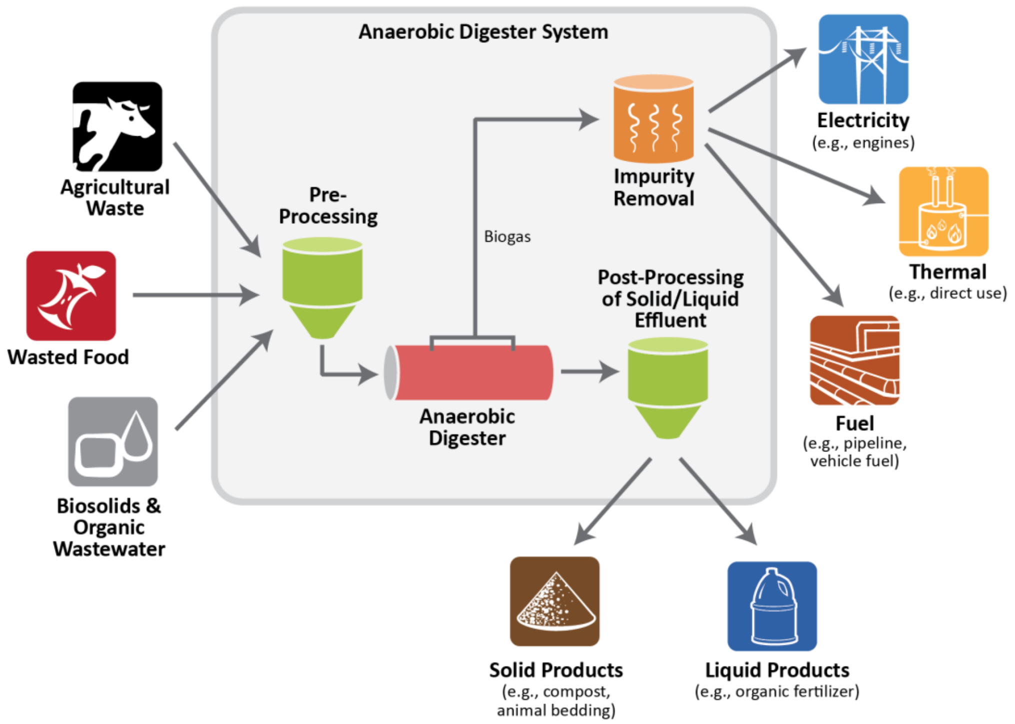

Figure 4. Anaerobic digestion process diagram. (Source: www.tn.gov)

In anaerobic digestion, sometimes abbreviated AD in literature, four different procedures occur at the same time all due to microorganisms. The first step, called hydrolysis, consists of the breakdown of the big molecules by bacteria for the other microorganisms to use (Dombrowski, 2018). With the degraded molecules (now soluble organic monomers of sugars and amino acids) and the use of the acidogenic bacteria, the substrate used in the

third stage is obtained during the second phase or acidogenesis phase, also known as the fermentation stage (Kamusoko et al., 2022).

As Parra Huertas (2015) explains, during the third step, also known as acetogenesis, all the substances that cannot be transformed into methane or carbon dioxide during acidogenesis, are converted into substances that can be modified. And finally, the last process known as methanogenesis obtains the final compounds that form biogas, mainly methane (CH_4) and carbon dioxide (CO_2). A diagram of the four phases summarized can be found in Figure 5.

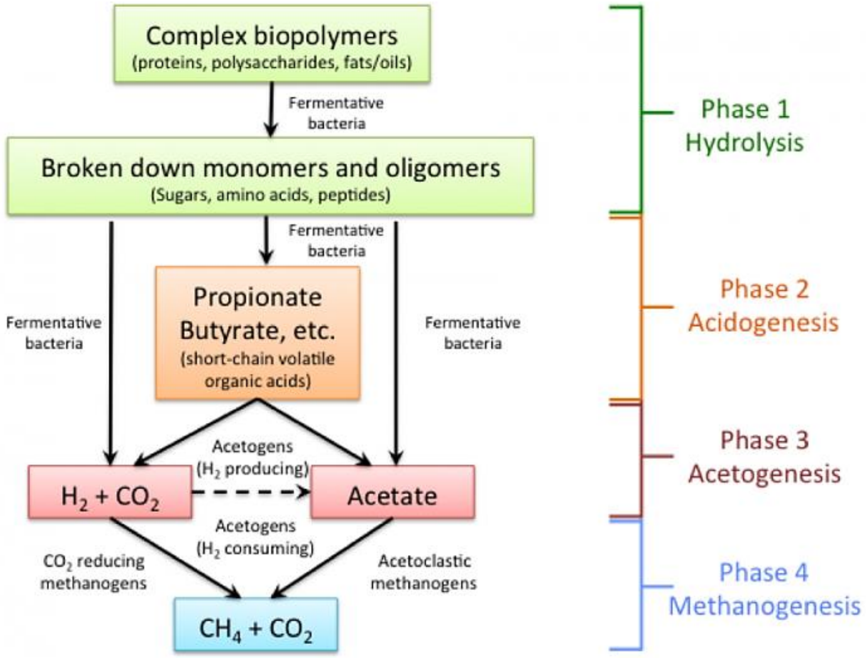

Figure 5. Anaerobic digestion phases scheme. (Source: www.e-education.psu.edu)

The final compounds generated from anaerobic digestion are used to obtain biogas and digestate. Biogas is mostly made of methane (CH_4) and some amounts of carbon dioxide (CO_2), hydrogen sulfide (H_2S), and vapour water (Zhang et al., 2016). If not purified, it can be used for the same purposes as natural gas, for example, heat and electricity generation. Whereas if it is undertaken by a purified process, it can be used as a transportation fuel (US EPA, 2019b).

The other final compound generated from the anaerobic digestion, digestate, is a mixture of liquid and solid substances. The compound is separated into those phases and based on which was the raw material used the solid part, the liquid part or even both can be used as fertiliser or compost. Although they have to be treated before those purposes (Renergon, 2021).

3 Chemical elements

As Newall (2022) defines it, sludge is a thick, wet, and viscous substance produced in industrial and refining processes that resemble wet soil. But referring to Stormossen Oy, the sludge they obtain is from the digestion either from biowaste or other residues, which during the thesis is differentiated as biowaste digestate and sludge digestate, respectively. This chapter introduces the present compounds analysed in both sludge digestate and biowaste digestate after the centrifugation process known as solid phases by Stormossen Oy.

3.1 Chemicals studied

The chemical compounds present in Stormossen sludge and biowaste digestate are shown in Table 1 below. The list of chemical compounds and their presence was provided by the thesis supervisor in Stormossen Oy, Johan Saarela, and it can be found in the **¡Error! No se encuentra el origen de la referencia.**.

Table 1. Chemical elements analysed in the sludge highlighted by their types: brown for metals, blue for non-metals, and white for semi-metals (Source: Stormossen Oy, **¡Error! No se encuentra el origen de la referencia.**)

Chemicals	Symbol
Manganese	Mn
Cadmium	Cd
Chromium	Cr
Copper	Cu
Mercury	Hg
Nickel	Ni
Lead	Pb
Zinc	Zn
Cobalt	Co
Potassium	K
Nitrogen	N
Phosphorus	P
Arsenic	As

As can be seen in **Table 1**, the compounds are mainly formed by metals, but also non-metals, and one semi-metal. Therefore, the definition of the compounds is divided by these groups.

3.2 Metals

According to Merriam-Webster Dictionary (2019), a metal is a chemical element that conducts electricity and heat and loses electrons. Also, these elements are usually malleable, ductile, and in a solid state. Most metals exist in minerals and not in their pure form. More than half of the chemical elements discovered are metals (Encyclopaedia Britannica, 2019h).

3.2.1 Manganese

Manganese, with the symbol Mn, is a chemical element discovered in 1774 by Johan Gottlieb Gahn and Carl Wilhelm Scheele (Encyclopaedia Britannica, 2019g). According to the Royal Society of Chemistry (2011d), this metal is the fifth most common one on Earth and is rarely used in its pure form because it cannot be found in its elemental form in nature (PubChem, 2023).

In different forms, this substance is used in industry to produce metals such as iron, aluminium, copper, nickel, and steel among others. Although it is also very important for the distinct life forms (Encyclopaedia Britannica, 2019g). Manganese is needed by some organisms to do photosynthesis, as fertiliser, or even as a food supplement for livestock animals and humans.

However, as stated in PubChem (2023), this metal is a flammable solid and when exposed to high amounts it can cause health problems. Also, it is important to take into consideration that it can be a risk to the environment since it harms aquatic life.

3.2.2 Cadmium

Discovered in 1817 by Friedrich Strochmeyer, cadmium (Cd) is a metal usually found in zinc, lead, and copper minerals. However, it can be also present in other compounds because it reacts easily with other elements (Dartmouth Toxic Metals, 2022).

As stated by Ross (2018), cadmium is mostly used in batteries (nickel-cadmium), but it can also be used in pigments, metal alloys, some electronics, and some plastics. Thanks to its ability to absorb neutrons, it is used in nuclear reactors too.

According to the Centers for Disease Control and Prevention (2020), also known as CDC, cadmium exposure is really easy to get as it enters the environment not only through the soil but also into the atmosphere. This causes people to eat plants and animals that have been exposed and therefore ingest cadmium. But also breathe air that contains it mostly due to tobacco smoke. The same source (Centers for Disease Control and Prevention, 2020) also states that high exposure to this metal can cause not only problems to the digestive and respiratory systems but also fragile bones and kidney disease.

And seeing the easiness cadmium has to get into the atmosphere, soil, and water, many ecosystems get endangered since animals like earthworms, fishes and shellfish absorb this element easily (Ross, 2018).

3.2.3 Chromium

Chromium is a transition metal identified by the chemical symbol Cr. It was discovered in 1780 by Nicolas Louis Vauquelin, and it was given this name because it gives a different colour to the compounds it can form. Like other metals, it is not found in its pure form but in minerals with other metals (Chemicool, 2012).

The uses of this element can go from making metal alloys to coating ceramics and other metals or using it in dyes and paints. It is also used in the leather industry as a dye (Lenntech, 2019a). Depending on which state the chromium is in, its uses vary. Those states are pure chromium, chromium (III) or Cr (III), and chromium (VI) or Cr (VI). And the difference between them is the oxidation state of the element (Royal Society of Chemistry, 2011a).

So say Sneddon (2016), whilst Cr (III) is needed by humans and its deficit may cause health problems, as well as high amounts of it. Chromium (VI) is highly toxic and can cause from skin rashes to death. However, the seriousness of the effects changes depending on how is the exposure. Both chromium oxidative states can have the same effects in animals and fishes since these types of Cr can end up in the soil and water. It can be also a problem for plants if they absorb great amounts of them. And it has to be taken into account that ‘contaminated’ plants, animals, and fishes can harm humans if they eat those (Lenntech, 2019a).

3.2.4 Copper

For more than 8000 years, copper (Cu) has been used by humans. This metal along with gold is one of the only ones with a natural colour different from grey or silver (Pappas, 2022). According to the Royal Society of Chemistry (2011b), copper can be found in nature in its elemental form, although it is more common to obtain it from ores.

Jefferson Lab Resources (2018) states that the main use for pure copper is in wires. However, since it is too malleable it is used together with other metals to form different alloys like bronze and brass. Those are used for making tools, decoration items, weapons, and even musical instruments. Whether it is used one type of alloy or the other, it depends on which characteristics the objects must have and which conditions they have to endure. Nevertheless, those are not the only uses for copper. Some of the chemical compounds it forms are used as catalysts, dyes, or even battery electrodes (Encyclopaedia Britannica, 2020).

Following Lenntech (2017b), copper is emitted into nature both from natural and human causes. Either way, those can be in the atmosphere or soil and water, and when released into the atmosphere, it precipitates with rain. As a result, humans can be exposed to copper through breathing and ingestion. But so says the Royal Society of Chemistry (2011b), it is needed for a correct cell function but if ‘taken’ in surplus, it is very poisonous.

3.2.5 Mercury

Quicksilver, or mercury, is a metal identified by the symbol Hg and it is known for being the only metal that is liquid at room temperature. For that reason and some other properties like volume expansion and high density, it was used in thermometers, barometers, and manometers (Encyclopaedia Britannica, 2023). However, as explained by the US EPA (2015), due to mercury’s toxicity both in the elemental form and in the vapour formed at also room temperature, those instruments cannot be bought anymore. Other uses for elemental mercury that are no longer on the market are batteries, electrical devices, and fluorescent lights (Lenntech, 2019d).

But even so, mercury can form other substances when mixed with other compounds and elements. Those ‘new’ mercury substances’ uses vary depending on what is paired up and

can go from medicine topical products to fungicides or even pigments (Encyclopaedia Britannica, 2023).

According to Lenntech (2019d), mercury is discharged into the environment from natural processes, mostly minerals exposed to environmental conditions. But human action is the main source of it. This is because mercury is usually found in minerals, therefore during the processes of obtaining the other metals they release quicksilver. But also, burning fossil fuels, waste, and others release this metal into the atmosphere, and will eventually precipitate in the soil and water (US EPA, 2015).

And when it reaches soil and water, it may react with other substances present forming even more toxic compounds that will affect plants and animals. And due to the eating chain, this mercury will, in due course, pass down to humans who ingest it mostly by eating fish. Consequently, if the exposure is high, it causes many health problems such as allergic reactions or even brain and nerve damage (Lenntech, 2019d).

3.2.6 Nickel

In 1751, Axel Cronstedt isolated a new metal from an ore and named it nickel, which is identified by the chemical symbol Ni (Royal Society of Chemistry, 2011e). So says the U.S. Geological Survey (2013), this metal can be extracted from two different mineral deposits, in one the nickel is paired with iron, and in the other with sulphur. Although it is supposed that the greatest amount of nickel is in the Earth's core.

Its main characteristics are oxidation and corrosion resistance, thermal and electrical conductivity and nickel also is strong and tough like iron (Encyclopaedia Britannica, 2019b). Due to those qualities, this metal has different uses. Based on the Nickel Institute (2020), the main application for nickel, with approximately 69% of the metal mined, is stainless steel production followed by battery manufacturing with 11% of the nickel extracted. Other uses are metal coating, fabrication of other types of alloys, and even as a catalyst for chemical reactions.

Even if this metal has multiple uses, nickel's presence in the environment is very low. But is emitted into the atmosphere as a pollutant by power and trash incinerator plants. Although it takes long periods, due to rain or just because the particles fall, that nickel

finishes up on the ground and surface water. Another way to get into surface water is from wastewater flows (Lenntech, 2019e).

In the Royal Society of Chemistry (2011e), it is stated that despite that it is undetermined how nickel plays a role in biology, it is essential for some organisms and it affects plants' growth. The same is explained in Lenntech (2019e) but specifies that its effects on humans are more studied than on other species, although, in all of them, low amounts of nickel are either needed or not damaging. When plants, algae, and microorganisms are exposed to high amounts of this metal due to the soil and/or water being 'contaminated' with it, their growth rate declines. Whereas high exposure to nickel in humans due to consuming contaminated water, breathing contaminated air and/or tobacco smoke, and eating foods containing high amounts of it, mostly some types of beans and tea, can cause health problems. Those can go from skin sensitivity and allergies to even heart and lung conditions or cancer.

3.2.7 Lead

Used since ancient times, lead identified with the chemical symbol Pb, is a metal that has been used for multiple uses due to it being durable, resists corrosion, and does not conduct electricity easily. Like other metals, it is mostly found in minerals although it is considered to be a scarce element (Encyclopaedia Britannica, 2019e).

In the past, according to the Royal Society of Chemistry (2011c), lead was used from simple uses like water pipes, pigments, or coin production to more complex applications like insecticides, hair dyes, or even as an additive in gasoline. But given that more recently it has been studied how lead affects negatively the human body, those uses have been banned. Nowadays, lead is used in lead-acid batteries for vehicles, as wrap in cables and wires, diving weights and anchors, alloys, and even in storages of liquid corrosives or in protection for X-rays and gamma-rays (Chemistry Learner, 2018a).

As stated by Lenntech (2019c) and briefly mentioned above, lead is no longer being used for some of its purposes. The reason why is that it is a health hazard for humans, specifically one of the four most health-damaging metals, and it contaminates the environment being that human activity increases lead concentration in nature. Following the same source, it

is stated that due to the extent of lead presence in nature (water, soil, and air), it is absorbed by the organisms present and it passes down the food chain, poisoning each one.

The main effects lead poisoning has on humans, according to Chemical Engineering World (2022), are brain, kidney, and nervous system damage, high blood pressure, and even behavioural changes.

3.2.8 Zinc

Identified as an element in 1746 but already known by Ancient Greece and Rome, zinc (Zn) is a metal found in ores, and when pure it is bluish-silvery-white (Royal Society of Chemistry, 2011i).

Given its physical and chemical properties, it has multiple purposes. Since it resists corrosion, zinc is used to cover steel, iron, and other metals to protect them or even different alloy production. Some of its compounds are used as pigments in paints, plastics, or cosmetics, but other compounds are used in fluorescent lightbulbs or television screens (Chemistry LibreTexts, 2015). Zinc is used in galvanic cells, lithium-ion batteries, and even one of its compounds is used as a type of surgical dressing that promotes healing the wound (Lawrence, 2022).

Encyclopaedia Britannica (2019d) states that zinc is an element essential to humans due to its role in the body. It is present in healthy red blood cells, in the pancreas to store insulin, and even in some enzymes to digest proteins. Therefore, both an under or over-intake cause health problems like stomach cramps, skin irritation, or even anaemia. The effects it has on animals and plants depend on which organism is and the amount of zinc absorbed. Because zinc is naturally present in nature, the concentrations they obtain are what those organisms need, but due to human activity, some waters and soils are polluted with zinc. This affects negatively plants because they cannot grow or animals and fishes get poisoned and if eaten, that high zinc concentration climbs up the food chain (Lenntech, 2019h).

3.2.9 Cobalt

Based on the Royal Society of Chemistry (2017), cobalt was not found as an element until 1739, but some of its compounds were used in Ancient Egypt and China as pottery glazes because of its colour. In its pure form, cobalt (Co) is a magnetic metal with a silvery-blue

colour and even though it is present in several minerals, it is mainly obtained as a byproduct in nickel refining.

So says the Encyclopaedia Britannica (2019f), this metal is used for manufacturing alloys when those need specific characteristics like being ferromagnetic at high temperatures, are needed to be elastic, or having to be used at temperatures near their melting points. Some cobalt compounds are also used industrially, either in glass and ceramics production, for manufacturing catalysts, or even for agricultural products. Another different use is in the medical field. The isotope Cobalt-60, which is radioactive, is used for treating cancer and in X-ray portable devices due to its gamma-ray emissions (Clark, 2013).

Cobalt is necessary for human health because it forms the vitamin B12 and since it catalyses red blood cell production, it is also used in anaemia treatment. But as with other metals, due to industrial activities, this metal is emitted into the environment and can be absorbed in excess by humans either from breathing or eating food with high cobalt concentrations. Therefore, having this excess has a negative impact on health like asthma, skin sensitivity, vision problems, or even thyroid and heart problems (Lenntech, 2019b).

3.2.10 Potassium

So says Encyclopaedia Britannica (2018), potassium (K) is a soft, silvery solid that conducts electricity and heat easily. This metal, isolated by Sir Humphry Davy in 1807, is the 7th element most abundant on Earth and the first one to be isolated by electrolysis. Potassium is needed by all living forms since it supports a balance between fluids and electrolytes in cells (Royal Society of Chemistry, 2011h).

About 95% of all the potassium compounds produced are used in fertiliser manufacturing, given that this metal is highly needed by plants to be able to do photosynthesis (Encyclopaedia Britannica, 2018). The rest is used for other uses like textile bleach, leather tanning, soaps, special glasses, ceramics, explosives, fuel cells and batteries, and food additives (Shi, 2021).

Humans obtain potassium from the intake of vegetables, fruits, meat, and dairy among others. Which when consumed in proper amounts, not only keeps a good physical fluid system but also a good nerve function. However, when high exposure to this metal, it

causes health problems. If it happens by ingestion of a high quantity of food that contains it, it causes low blood pressure and even arrhythmic heartbeats. If it occurs by being in contact with its compounds, it can cause irritation in the respiratory system or even fluid build-up in the lungs if breathed, skin and eyes irritation, or even burns (Lenntech, 2019g). An insufficient potassium level, although it is more difficult to occur, can cause arrhythmia, fatigue and even muscle paralysis. Both high and low concentrations of potassium are caused by kidney damage, since kidneys are the organs responsible for eliminating this metal's excess in the body (Harvard School of Public Health, 2019).

3.3 Non-metals

As the name indicates, a non-metal is a chemical element that does not present the characteristics of those that are metals (Dictionary, 2023). Meaning it does not conduct heat nor electricity and is neither malleable nor ductile. Those elements can be either gases, solids, or liquids. Moreover, non-metals form negative ions by gaining electrons (Helmenstine, 2007). They represent a minority in the periodic table.

There are only two non-metal compounds found in the Stormossen Oy sludge and biowaste digestate, nitrogen and phosphorus.

3.3.1 Nitrogen

Isolated and identified by Daniel Rutherford in 1772, nitrogen (N) is an element that mostly presents as a diatomic molecule (N2), which is an odourless and colourless gas. It forms approximately 78% of the volume of the atmosphere and is present in the DNA, RNA, and all proteins (Royal Society of Chemistry, 2011f). Which indicates that it is present in all living forms.

As Sanderson (2019) remarks, nitrogen is obtained by distilling liquid air. After, it is either used to manufacture ammonia and later other chemical compounds or liquefied. The compounds produced are used in the electrical and metal industry, and the production processes for fertilisers, fumigants, dyes, rocket fuel, plastics, explosives, etc. When liquefied, nitrogen is used in the medical field and in the food industry to preserve biological samples and foodstuffs, respectively (GeeksforGeeks, 2021).

According to Lenntech (2019f), nitrates and nitrites (both different compounds containing nitrogen) are present in soil and water, but human activities such as the widespread use of fertilisers and increased combustion processes have increased their concentrations. This increase can cause environmental problems. Because some living organisms are affected by high nitrogen levels very easily, they can go through biological changes, therefore even having their DNA changed and transforming into new species. Regarding animals and humans, high nitrogen ingestion can cause a reduction of the ability of the red blood cells to transport oxygen and a vitamin A shortage. If breathed, rapid pressure changes cause decompression sickness and can result in death (Sanderson, 2019). In plants and algae, nitrogen helps their growth, but when it is present in high concentrations in waters it causes eutrophication (GeeksforGeeks, 2021). This is when there is an overgrowth of plants and algae causing the disappearance of the other ways of aquatic life in the affected area (NOAA, 2021).

3.3.2 Phosphorus

Discovered in 1669 by Hennig Brand, phosphorus (P) is a non-metal element that due to its high reactivity with other elements, is not present in its pure form in nature. The most common form it presents is in minerals, and there is where it is obtained from (Encyclopaedia Britannica, 2019c).

Phosphorus' main characteristics include being solid at room temperature and a poor electricity and heat conductor. But because there are 10 different forms (named after their colour) in which it can exist, their qualities are different and so are their uses. The predominant form is called white or yellow phosphorus. It has a waxy appearance and is very reactive, it ignites spontaneously in contact with air so it has to be stored in water (LibreTexts, 2013). As mentioned by the Royal Society of Chemistry (2011g), there is another form that is very common, red phosphorus. This allotrope is more stable and it is not toxic like white phosphorus.

Although each phosphorus allotrope has different properties and therefore it is more suitable for one use or another, this element is used in different production processes. Those can be for fertilisers, pyrotechnics, insecticides, additives in gasoline or detergents, alloys, chemical synthesis, and others (Encyclopaedia Britannica, 2019c).

Lenntech (2000) declares that phosphorus is an element present in DNA, so it is present and needed by all organisms. However, excessive exposure to its compounds can cause environmental and health problems, like osteoporosis or kidney damage. Given that this element is widely used in industry and agriculture, it is more easily emitted into the environment where usually ends up in surface waters. There, when in high concentrations, can cause an overgrowth of aquatic plants and algae followed by the disappearance of the other aquatic life forms in the area affected (US EPA, 2013).

3.4 Semi-metal

As stated by Collins Dictionary (2023), a semi-metal is a chemical that has characteristics from both metal and non-metal elements and can also be named a metalloid. This means that metalloids are usually good semiconductors and in a solid state. Even though they reflect light like metals, there are semi-metals that have different forms and some appear non-metal (Helmenstine, 2019).

In Stormossen Oy's biowaste and sludge digestate, only one semi-metal is found, arsenic.

3.4.1 Arsenic

So says Greene (2022), arsenic (As) is an element identified in the 13th century by Albert the Great, although it was used in Ancient Greece and Rome in poisons and medicine. Due to its scarcity and being mostly in minerals mixed with other elements, arsenic is mostly obtained as a byproduct from lead and copper refining processes (Chemistry Learner, 2018b).

This metalloid is present in three different forms, although the most common one is called grey arsenic, which conducts electricity and is a shiny metal. The other two allotropes are known as yellow and black arsenic. Both are non-metallic and do not conduct well electricity and their appearance is soft and waxy for the yellow and brittle and glassy for the black (ThoughtCo, 2019). Depending on the purpose wanted for the products containing arsenic, the form or the compounds used are different. According to Encyclopaedia Britannica (2019a), arsenic is used in some alloys to give them thermal properties, mechanical properties, and even corrosion resistance. It is also used in

pyrotechnics, pesticides, semiconductor elements, metal adhesives, and even in wood preservatives.

Arsenic is, as mentioned before, very toxic, and scarce. However, due to human activity, it is more widely spread in the environment. This means it can be found in water, soil, and air, therefore it is easier to be exposed to it. Lenntech (2017a) states that arsenic exposure for humans either from breathing air, drinking water, having skin contact with soils that are contaminated with this semi-metal or even eating As-containing fish and seafood, can cause several health problems. Those issues and their intensity vary depending on the amount and the duration of the exposure. Some of said health problems are reduction of white and red blood cell production; lung, stomach, and intestines irritation; skin disorders; increased possibility of developing cancer; and even DNA damage.

4 European Legislation

According to the European Union (2023), European legislation can be divided into five different types: regulations, directives, decisions, recommendations and opinions. Each one is applied differently, meaning they can specify which EU countries must follow them (if not all) and how to do it. Below, those categories are explained together with some examples.

Regulations

When regulations are passed, all countries forming the European Union must execute them as they indicate. Therefore, a regulation is an act of compulsory application for all the European Union countries.

One example is the Regulation (EU) 2023/1542 of July 12th, 2023, about the information, labelling and safety among other characteristics of batteries that will be sold in the European Union so when those are considered waste their impact on the environment and health will be decreased (EUR-Lex, 2023e).

Directives

Like regulations, directives are laws that must be followed in all EU countries. Though there is a main difference: each country decides how to achieve it. This is due to directives being targets to accomplish before a date.

To give an example, Directive (EU) 2018/2011 of December 11th, 2018, determines how to encourage energy use from renewable fonts and in which cases its use can be supported financially. These objectives should be achieved by 2030 (EUR-Lex, 2022).

Decisions

Unlike regulations and directives, decisions are obligatory to follow only by the countries or even companies they are referred.

One example would be the Commission Decision of February 10th, 1998, in which it was accepted the tracking plan Finland submitted to detect residues in both live animals and animal produce (EUR-Lex, 2023b).

Recommendations

As opposed to the other law types and as its name suggests, when the European Union makes recommendations, the countries do not have to obey them. And if they want to, they choose how to apply them.

An example would be Recommendation C (1998) 2163 of July 22nd, 1998. It is about how changes can be made to domestic laundry soap (packaging, ingredients, use instructions, etc.) to decrease their impact on the environment (EUR-Lex, 2023c).

Opinions

These statements are made by the primary European Union institutions as well as the Regions and the European Economic and Social committees. They give their point of view about their fields while laws are being created.

Whereas regulations, directives, and decisions are binding and have legal consequences when they are not pursued, both recommendations and opinions are not.

4.1 Regulation (EU) 2019/1009

The Regulation (EU) 2019/1009 (EUR-Lex, 2023d) written on June 5th, 2019, and last modified on March 16th, 2023 (EUR-Lex, 2023a) establishes the characteristics an EU fertilising product (has the CE marking) must have, how to be labelled and from which sources it can be produced. Said product can be distributed only if it follows this regulation.

According to this Regulation, a fertilising product is defined as any material whose purpose is to be used on plants, mushrooms, or their surroundings and the part where their roots grow to supply them with nutrients and increase their nutrition efficiency.

Following Annex I from Regulation (EU) 2019/1009, there are seven main categories, with their related subcategories, into which EU fertilising products can be divided. In total, there are 33 different types. These main categories, which are labelled as Product Function Categories PFCs) are as follows:

1. Fertilisers
2. Liming materials
3. Soil improvers
4. Growing mediums
5. Inhibitors
6. Plant biostimulants
7. Fertilising product blends

In Part II of this same Annex (Annex I), it is established the characteristics, and maximum concentration of chemicals and microorganisms, which the second ones are not always needed, each type of EU fertilising product must have to be considered so.

In the second annex of the Regulation, there is a list of 15 materials that can be used to make those fertilising products and a detailed process those have to be treated with to be able to be used for this purpose.

Annex III specifies how to label EU fertilising products according to which category they belong to, and Annex IV clarifies the methodology that has to be used to perform a conformity assessment based on what is defined in Annexes I and II.

4.2 Document Evaluation on the Directive 86/278/EEC

On May 22nd, 2023, a Document Evaluation (EUR-Lex, 2023f) was published about the Directive 86/278/EEC, published on June 12th, 1986. Said Directive was written to regulate the use of sewage sludge in agriculture to avoid damaging consequences for the environment and humans when not done correctly.

Since the Directive was made public it has not been changed significantly, and there has been an evolution in how this sludge is treated and even in how wastewater is treated, therefore transforming the obtained sludge. For this reason, a Document Evaluation was done by studying how useful the Directive has been.

The Evaluation concludes that the Directive seems to have been effective, although the difficulties in obtaining data and the stricter requisites some EU member states have implemented challenge to differentiate, for some countries, which is the cause of the effectivity. In addition, it was not possible to determine if there have been or will be long-term problems because of using sewage sludge in agriculture because of the absent data throughout all these years.

Finally, it recommends revising the Directive and adapting it to the technologies used nowadays, since they may change the sludge composition. And also, to look after other plans and strategies made since.

5 Market research

After extensive research, only one European project was found that had requirements to be able to be helpful for thesis commissioner, Stormossen Oy. The project, called 'SYSTEMIC', consists of 5 European anaerobic digestion plants where each implements a different type of valorisation of the waste treated (SYSTEMIC, 2021a). Other European

plants that are interested in the project and meet the criteria asked are considered associated plants. One of those is Stormossen Oy (SYSTEMIC, 2020a).

Participating in this program, there is an Italian company, called Acqua & Sole, that shares some characteristics with Stormossen Oy. Those common characteristics are treating the sewage sludge and using anaerobic digestion technology (SYSTEMIC, 2020b).

Located in Vellezzo Bellini (Pavia, Italy), Acqua & Sole is a company focused on circular economy by treating waste and obtaining energy from non-traditional sources. Also, it uses byproducts of organic waste treatment to obtain substances that are essential in agriculture (Aqcua & Sole, 2023). Furthermore, this company is part of a project called 'Biomass Hub', which is sponsored by the European Union and the Lombardy Region (Aqcua & Sole, 2020).

Said project focuses on how to obtain energy, biofuels, and fertilisers (among others) from waste considered 'organic' (biowaste from municipal solid waste, sludge from wastewater treatment plants and waste obtained in agricultural processes). This project is carried on by both public and private entities (Lombardy Energy Cleantech Cluster, 2019).

Regarding Aqua & Sole, and its purpose, according to SYSTEMIC (2018), it uses mainly sewage sludge and digestate from treating food waste out of municipal solid waste. And it obtains ammonia sulphate and fertiliser from them after carrying out the treatments needed. After, the final wanted products are produced. Also, from the digestion of the food waste, it obtains biogas that afterwards is transformed into electricity and thermal energy. In Table 2, a summary of this information can be seen.

Table 2. Resumed process from Acqua & Sole (Source: https://systemicproject.eu/)

Raw material	Treatment	Final product
Sewage sludge, agricultural waste, food waste	Anaerobic digestion, nitrogen recovery	Biogas, organic fertilisers, soil improvers, ammonium sulphate

Even though this company is private, and the information above about its treatments, source materials and final products is reduced, it is a bit more detailed on SYSTEMIC's web page. Although not as much as it would be liked.

According to SYSTEMIC (2021b), nitrogen recuperation is done so that two different products are obtained from only one process. Those products are ammonia sulphate and a digestate after the anaerobic digestion with low nitrogen concentrations.

The area where Acqua & Sole is located (Pavia, Italy) mainly cultivates rice, around 40% of the Italian rice crops are located there (Mondo Macchina, 2014). It is in those crops where the ammonium sulphate is used as a nutrient whilst the digestate with low nitrogen content is used in crops where there is a limitation on the nitrogen present in the fertilisers used (SYSTEMIC, 2021b).

6 Discussion

Regarding the initial aims and objectives

This thesis aimed to determine if the sludge digestate obtained by Stormossen Oy could be used in agriculture. This goal was met by setting four objectives and fulfilling them.

The first objective was to identify the end-products present in Stormossen Oy's sludge digestate. To do so, it was asked Johan Saarela, project development manager at Stormossen Oy, if it was possible to obtain a list of the substances present in the sludge digestate. After getting a list of the chemicals and microorganisms analysed, and therefore present, in the final sludge digestate obtained, literature research about those chemicals was done to mainly determine their uses and their impact on the environment and humans. As a result, this objective was fulfilled, although not completely since in the end it was decided not to read up on the microorganisms analysed.

The second objective, review European Union's legislation about sludge digestate in agriculture, was also achieved seeing that it was found a Regulation on the characteristics of all the fertilising products in the European market.

The third objective consisted of investigating what other European countries do with sludge digestate in agriculture obtained from similar processes. This objective was also reached since a company was found that the before-mentioned conditions apply.

Finally, the last objective was to make a recommendation for Stormossen Oy about what can they do with the sludge digestate obtained to use in agriculture. It was completed by considering the information found for achieving the second and third objectives.

Regarding the limitations to the work

There was one main constraint found during the process of writing the thesis. This was to find information about how companies in other European countries use sludge digestate in agriculture, and that said digestate was produced in a similar way it is done in Stormossen Oy. After doing a lot of research, only one company (Italian) was found that could be used as an example, and only because it is part of a European project. Even so, the information found was very limited, only from the European project web page not from their web. This information was not only general and not clear with how and which raw materials they process but also it is from 2018. So it is not possible to know if they still apply the same techniques or treat the same materials.

Given that only one company was found, it was not possible to compare what is done in other businesses or countries.

Regarding the consistencies and inconsistencies

The aims and objectives of this thesis have changed along the process making so that they would be narrowed down. This is because what was asked from Stormossen Oy was very general and to write this thesis and obtain reasonable goals, objectives and foremost suggestions for the company, it was decided to choose one sector. This area chosen, agriculture, was motivated by the use they give the digestate obtained from biowaste.

Additionally, the limited information found on real scenarios with similar characteristics did not enable comparing different examples or obtaining clear information. Which led to not being able to give a realistic suggestion to Stormossen Oy based on those.

7 Recommendations for Stormossen Oy

Considering all the results obtained from the research realised so that the aims and objectives of this thesis were met, its conclusion will be presented as a recommendation for the thesis company commissioner, Stormossen Oy. Said recommendation will be mainly based on the European legislation found on the topic, of sludge digestate in agriculture, although the real case found will also be considered.

Considering the Regulation (EU) 2019/1009 about the characteristics an EU fertilising product must have, and its latest modification from March 16th, 2023, Stormossen Oy cannot use the digestate obtained from treating sewage sludge and used cooking oil with an anaerobic digestion (sludge digestate) as any fertiliser type. Instead, according to this Regulation, only the sewage sludge before digesting could be used to obtain precipitated phosphate salts and their derivates. Following, these salts could be used in the production of fertilisers of any type. Moreover, it is not clear how cooking oil could be used or treated to obtain these products because this substance is not mentioned in the Regulation.

Regarding the only real case with similarities to Stormossen Oy's characteristics, Acqua & Sole, given the limited information found it is not clear which sources from those treated are used for obtaining which product, as commented in the discussion section. Therefore, it can be used to know that it is possible to use sewage sludge for obtaining products for manufacturing fertilisers and soil improvers, but not for knowing the processes carried out with which materials to obtain those products.

Future research could be conducted to determine the economic and ecologic benefits of treating sewage sludge to obtain precipitated phosphate salts and their derivates. Also, more extensive studies of the European regulations and laws could be helpful in determining the usage of cooking oil in the process. Additionally, a case that has not been studied during the thesis and could benefit as intended, would be to conduct a treatment of sewage sludge to obtain precipitate phosphate salts and afterwards do an anaerobic digestion to still obtain biogas from it.

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9 Appendix

Below can be seen five different tables where it shows the chemicals and microorganisms analysed in Stormossen Oy from both digestates obtained from their processes: biowaste and sludge digestate. In those, BR1 refers to the sludge digestate and BR2 to the biowaste digestate. These tables were obtained thanks to Johan Saarela, project development manager at Stormossen Oy. (Note: some terms have been translated into English since they were obtained in Swedish).

BR1 (MMM24/11)	Mn	Cd	Cd max	Cr	Cr max	Cu	Cu max	Hg	Hg max	Ni	Ni max	Pb	Pb max	Zn	Zn max	Co	As	As max	TS%
2011		1.1	1.5	26.2	300.0	241.7	600.0	5.2	1.0	26.8	100.0	26.5	100.0	660.0	1,500.0	10.9	3.3	25.0	30.6
2012		0.9	1.5	28.2	300.0	252.0	600.0	0.5	1.0	32.1	100.0	19.0	100.0	742.0	1,500.0	10.8	4.3	25.0	29.6
2013		0.7	1.5	25.3	300.0	214.2	600.0	1.0	1.0	23.7	100.0	14.1	100.0	526.7	1,500.0	8.2	3.7	25.0	24.0
2014		0.9	1.5	41.0	300.0	265.9	600.0	0.6	1.0	29.3	100.0	19.8	100.0	615.0	1,500.0	13.2	4.6	25.0	27.2
2015		0.9	1.5	29.7	300.0	329.0	600.0	0.6	1.0	32.3	100.0	13.5	100.0	743.0	1,500.0	13.3	4.9	25.0	25.8
2016		0.7	1.5	19.1	300.0	270.9	600.0	0.4	1.0	27.4	100.0	11.3	100.0	524.5	1,500.0	11.6	3.8	25.0	27.1
2017		0.5	1.5	19.1	300.0	246.6	600.0	0.3	1.0	25.8	100.0	9.6	100.0	595.0	1,500.0	10.6	3.4	25.0	26.6
2018		0.5	1.5	20.7	300.0	257.7	600.0	0.3	1.0	30.8	100.0	11.1	100.0	480.0	1,500.0	11.9	3.0	25.0	26.0
2019		0.5	1.5	19.4	300.0	264.5	600.0	0.3	1.0	26.9	100.0	9.7	100.0	558.3	1,500.0	22.8	3.4	25.0	36.3
2020	441.7	0.6	1.5	17.3	300.0	293.3	600.0	0.3	1.0	25.7	100.0	9.8	100.0	589.0	1,500.0	45.9	3.6	25.0	25.4

BR2 (MMM24/11)	Mn	Cd	Cd max	Cr	Cr max	Cu	Cu max	Hg	Hg max	Ni	Ni max	Pb	Pb max	Zn	Zn max	Co	As	As max	TS%
2011		0.7	1.5	33.8	300.0	120.7	600.0	0.4	1.0	16.7	100.0	52.0	100.0	438.3	1,500.0	4.2	5.8	25.0	29.4
2012		0.7	1.5	36.5	300.0	116.4	600.0	0.4	1.0	18.0	100.0	62.5	100.0	588.0	1,500.0	4.6	6.3	25.0	28.5
2013		0.6	1.5	24.4	300.0	93.6	600.0	0.8	1.0	14.1	100.0	22.6	100.0	475.6	1,500.0	4.3	5.8	25.0	28.8
2014		0.6	1.5	26.3	300.0	81.2	600.0	0.3	1.0	13.3	100.0	38.7	100.0	314.2	1,500.0	3.4	5.9	25.0	29.4
2015		1.1	1.5	24.1	300.0	95.2	600.0	0.3	1.0	13.7	100.0	33.9	100.0	462.2	1,500.0	4.7	5.1	25.0	28.7
2016		0.6	1.5	26.1	300.0	102.6	600.0	0.2	1.0	14.8	100.0	26.7	100.0	392.7	1,500.0	5.8	5.2	25.0	27.6
2017		0.4	1.5	30.3	300.0	79.4	600.0	0.2	1.0	14.1	100.0	26.3	100.0	373.3	1,500.0	5.1	3.6	25.0	27.7
2018		0.4	1.5	24.8	300.0	94.5	600.0	0.2	1.0	14.3	100.0	29.8	100.0	549.1	1,500.0	4.6	2.9	25.0	25.4
2019		0.2	1.5	14.7	300.0	57.7	600.0	0.2	1.0	6.4	100.0	9.3	100.0	194.3	1,500.0	9.8	1.9	25.0	26.4
2020	243.4	0.2	1.5	11.1	300.0	46.4	600.0	0.2	1.0	4.0	100.0	12.0	100.0	177.4	1,500.0	6.2	2.3	25.0	26.3

BR1	Nitrogen, g/kg ts	Phosphorus, g/kg ts	Soluble phosphorus, g/kg ts	Potassium, g/kg ts
2011	25.0	28.4	0.1	3.2
2012	29.3	25.4	0.4	2.6
2013	33.4	30.0	0.2	2.5
2014	33.8	28.6	0.2	2.6
2015	36.4	31.3	0.6	1.8
2016	34.6	27.1	0.3	1.6
2017	34.6	26.1	0.1	1.4
2018	35.3	24.7	0.1	1.7
2019	32.1	28.5	0.1	2.0
2020	34.3	27.4	0.1	1.6

BR2	Nitrogen, g/kg ts	Phosphorus, g/kg ts	Soluble phosphorus, g/kg ts	Potassium, g/kg ts
2011	27.5	16.0	0.1	3.8
2012	24.8	11.9	0.3	4.9
2013	31.4	10.1	0.2	3.9
2014	27.5	10.7	0.3	5.0
2015	35.6	11.3	0.5	5.3
2016	33.0	11.2	0.3	5.4
2017	33.6	11.6	0.2	6.0
2018	39.6	13.1	0.2	5.6
2019	34.2	15.0	0.2	5.2
2020	37.8	11.7	0.1	5.7

BR1	Salmonella positiva prov %	E.coli (presumptiv) st/g	Coliform bacteria st/g	Thermotolerant coliform bacteria st/g	Enterococcus	Clostridium perfringens preliminär
2011	67	13,605	2,508	4,967	3,427	14,700
2012	60	17,470	10,291	21,333	12,083	61,086
2013	36	42,882	27,452	27,933	23,051	441,182
2014	75	66,653	18,973	69,654	349,900	389,167
2015	30	4,529	5,144	4,558	31,533	272,280
2016	70	113,581	63,364	146,581	85,700	211,700
2017	83	75,045	64,273	75,045	125,400	283,250
2018	45	157,768	62,568	157,868	109,391	299,727
2019	0	825	913	825	13,373	303,333
2020	0	48	42	42	18,334	225,333

BR2	Salmonella positiva prov %	E.coli (presumptiv) st/g	Coliform bacteria st/g	Thermotolerant coliform bacteria st/g	Enterococcus	Clostridium perfringens preliminär
2011	83	107,202	10,500	163,520	60,400	14,660
2012	90	12,646	38,830	221,448	46,456	3,822
2013	88	4,046	5,242	2,838	10,399	133,500
2014	92	9,618	8,267	12,271	2,089	37,950
2015	33	2,830	5,253	2,873	2,447	19,011
2016	64	1,463	1,650	1,281	3,636	6,148
2017	50	1,175	3,009	1,175	7,593	7,010
2018	64	1,215	133	1,215	23,545	8,637
2019	50	71	377	71	103,309	45,883
2020	25	138	636	148	248,778	50,775