Mémoire

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Enhancement of Luxembourg Wastewater Treatment Plant for the Biogas Production and Efficient Energy Recovery: Case Study of Bleesbruck, Mersch and Echternach

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ABSTRACT

A study has been done on three Luxembourg wastewater treatment plant producing biogas in order to evaluate their efficiency in term of energy. Some methods to improve the biogas production has been analyzed. Co-digestion done with appropriated co-substrates have shown significant increase of the biogas production as well as the energy self-coverage of these plants. Most of the pre-treatment methods analyzed have not shown a significant improvement of biogas production and would require some significant investment costs.

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To my mother who is already resting in peace, this achievement is yours.

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1 Introduction

1.1 Background

Energy usage has become one of the main topic and challenge in the modern era since the last century. It is now clear and agreed by the scientific community that natural fossil energy reserves are drying up. It is therefore urgent not only to find new source of renewable energy but also to find efficient processes that could help reducing the needs of external sources of energy.

Wastewater Treatment Plant (WWTP) are a good example. Indeed, the main goal of WWTP is process wastewater used by households or industry and transform that wastewater into reusable water flowing to the water pipelines. The primary goal being to take care of water reusage since the source of water are not infinite and it is sometime very difficult or even impossible to bring water from sea or oceans into the continent. However, processing wastewater within a WWTP requires a lot of energy.

Biogas generation from the sewage sludge of WWTP is a way to produce renewable energy from the wastewater treatment. The biogas produced by WWTP can be transformed into different forms of energy (heating, electrical energy, etc …). That energy can be used in order to reduce the overall WWTP energy demand. The ideal case would be having autonomous WWTP in term of energy, which means that the overall energy demand of the WWTP is totally compensate by the energy produced from the biogas. Nowadays, modern WWTP have an energy production self-coverage between 50% and 100% of their overall energy demand.

1.2 Aims of the work

The goal of this study is to perform a state of the art of three Luxembourgish WWTP located at Bleesbruck, Mersch and Echternach and to make suggestion that will help to optimize the biogas production and the energy self-coverage of each of these WWTP.

1.3 Structure of the work

Within the next section, a state of the art will be done in order to provide some main characteristics of the three WWTP related to the present study. An analysis will be done in order to evaluate the main drivers of WWTP for the energy efficiency purposes. The fourth section will be related to suggestions for the energy production optimization. An analysis is performed within that section in order to evaluate the outcome in terms of energy efficiency and energy self-coverage if the optimization processes are applied within these WWTP.

2 State of the art

Sewage sludge is the residue produce by WWTP. With the increase of the overall population over the last decades, it is expected that the wastewater processed by the WWTP will significantly increase during the coming years. The increase of sewage sludge will become an issue as there is a need to find an efficient way to process them. Main methods that were still recently used to process them are agricultural usage, landfill and incineration. However, these methods are very costly in term of environment protection and energy usage.

Anaerobic digestion is an economical and environmentally friendly technology for processing different organic waste including sewage sludge (Lise Appels, 2008). Using the anaerobic digestion, it has been shown that in the absence of oxygen, the organic waste could be biologically degraded and converted into a form of biogas, and other energy rich organic compounds as end products (Hanum, Chang Yuan, Kamahara, & Abdul Aziz, 2019).

The biogas extracted from the organic waste can be converted to different forms of energy. Depending on the quality of the biogas generated, suitable energy recovery technics can be used in order to convert that biogas into energy. Usually, the biogas is converted into heating, electricity, or natural gas for vehicle (NGV).

Within the first section, we will elaborate on the principles of the anaerobic digestion of sewage sludge within a WWTP. Later one, we will discuss on the different technics used to enhance the methanation process. Energy recovery technics are discussed within the last section of this chapter in order to show how the biogas generated is used in our daily life.

2.1 Conventional WWTP description

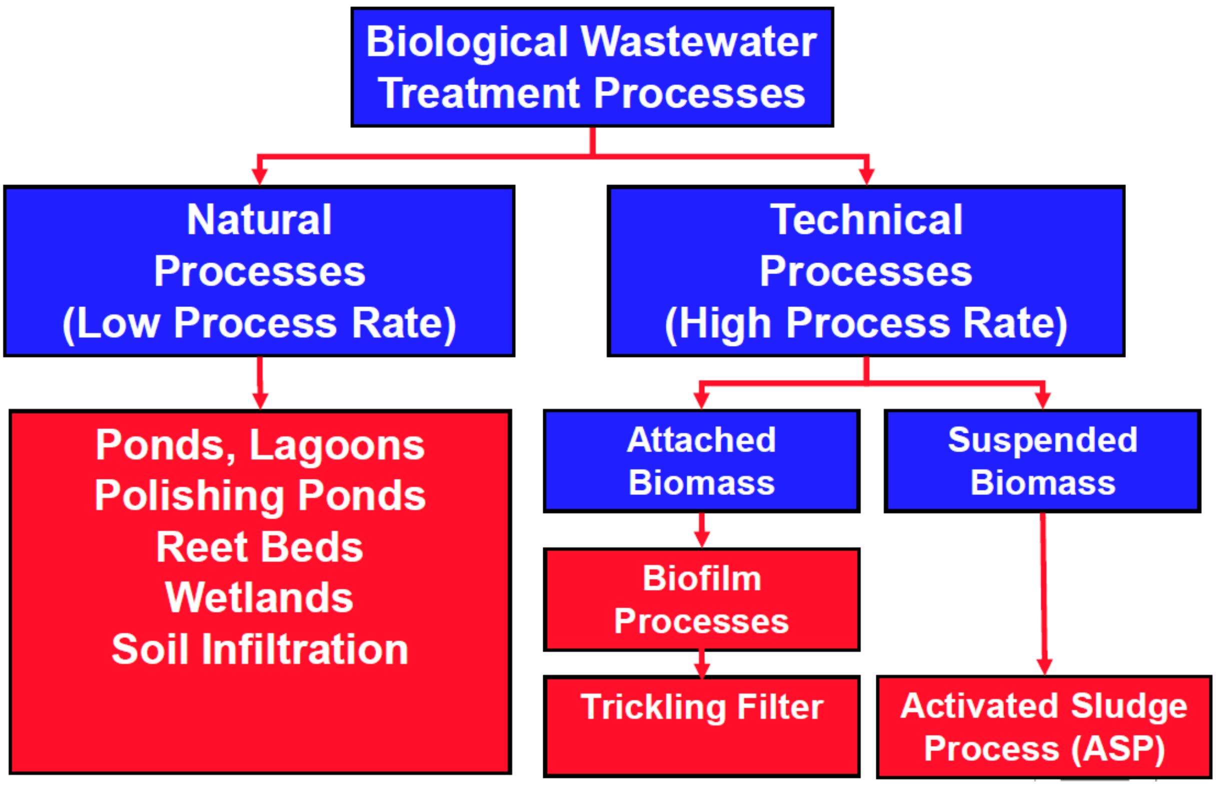
Due to the global warming and its damaging consequences on the planet and the ecosystem, it has become more and more important to find adequate processes that will help not only to protect the nature, but also to reduce the amount of carbon released due to human activities. The wastewater treatment is participating to that goal.

Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. Anaerobic digestion is generally used within the wastewater treatment plan in order to reduce the amount of sewage sludge, get rid of the micropollutants and to produce biogas and digestate. Prior to the anaerobic digestion, there are generally some primary and biological treatments.

The biological treatment can be done either following a natural process or following a technical process. Natural processes are usually done within:

- Ponds
- Lagoons
- Polishing ponds
- Reet beds
- Wetland
- Soil Infiltration

The technical processes require an industrial environment. Below, the different biological treatment are summarized:



The WWTP processes can be summarized as below:

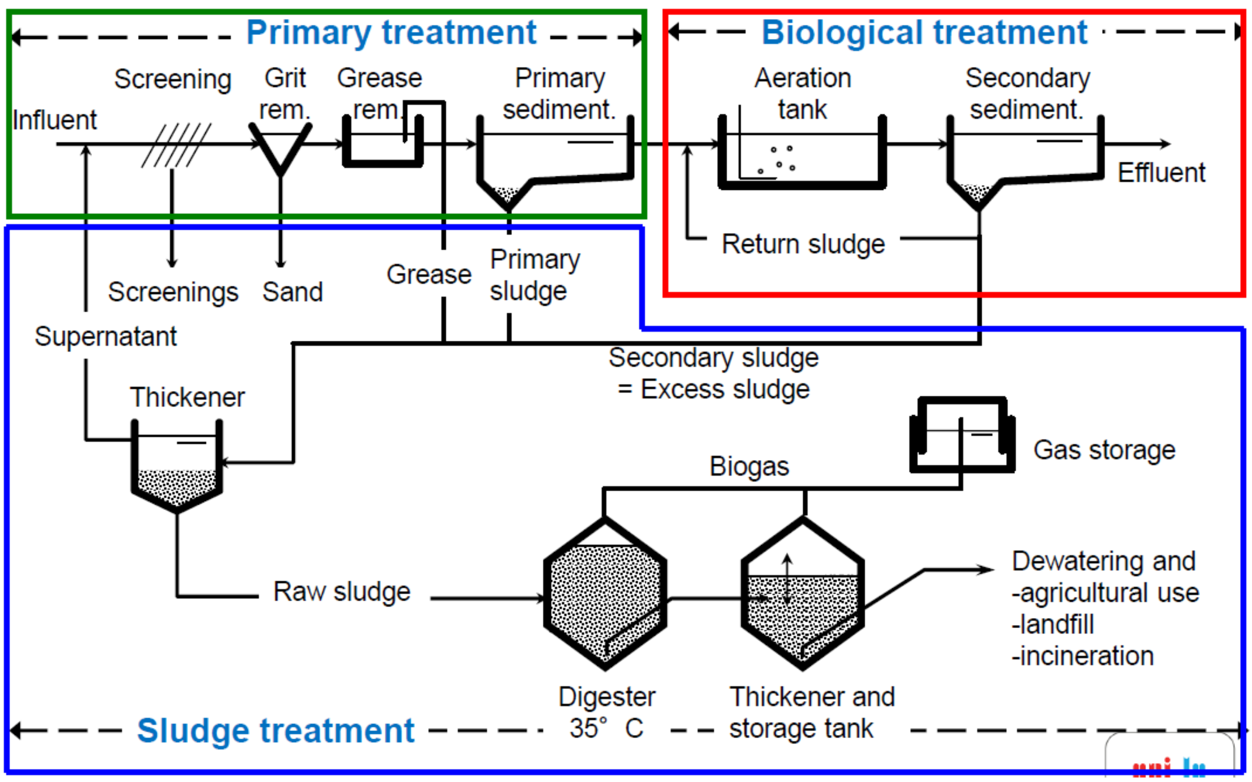


Figure 1: High level Diagram of a WWTP

There are three main blocks within a WWTP:

- The primary treatment block,
- The biological treatment block,
- The sludge treatment block.

2.1.1 Primary treatment

The primary treatment block can be split in three main steps:

- The screening is necessary to get rid of the large pollutants as woods, plastics, hygienic article and cans. It is important to eliminate these pollutants in order to smooth the downstream operations and equipment's, particularly for the pumps that could be damaged with these large pollutants. By removing these large pollutants, one could get a good sludge quality useful for agriculture.
- The grit chamber which is often combined with grease trap aims of removing grit material as sand, fine gravels and other mineral matter. The goal is to prevent abrasion of mechanical equipment and to avoid having grit deposits either in pipes, in digesters or in aeration tanks.
- The primary sedimentation tank main target is to remove organic settleable solids and to thick primary sludge (which are energy rich and can be converted into biogas) at bottom of tank.

The primary treatment has as input the influent coming from wastewater and is producing as output:

- The primary sludge which are later converted into biogas.
- The excess sludge which can be later processed using a biological treatment before being converted into biogas.
- Mineral waste as sand and other waste as grease.

2.1.2 Biological treatment

The biological treatment is usually done in two main steps:

- The aeration tank also called activated sludge tank is mainly using bacteria in order to eliminate the dissolved material. The main goal being the increase of the amount of activated sludge. This process can occur using aerobic or anaerobic conditions depending on the targeted goal and the wastewater characteristics.
- The secondary sedimentation tank is responsible of separating the activated sludge from wastewater via the sedimentation. Small Part (return sludge) of the activated sludge is recycled and sent back to the aeration tank, while the main part (excess sludge) is used to generate the biogas.

The biological treatment can be done either using natural methods or using technical ones. The natural methods are generally used for small communities while the technical ones are generally used for larger communities.

The natural methods are based on natural processes (same as the one within the nature) which are usually low process rates and require low amount of bacteria.

The technical methods which are usually high rates methods are generally done using biomass (attached or suspended). The technical methods are using biological treatment processes in order to eliminate wastewater pollution by biological activity (use of bacteria). This is done reducing the dissolved matter in wastewater (the amount of carbon, nitrogen and phosphorus).

The biological treatment takes as input the excess sludge coming from the primary treatment as well as the return sludge coming from the secondary sedimentation and is producing as output the effluent in one side and in other side the secondary or excess sludge that is used for the biogas conversion.

2.1.3 The sludge treatment

The sludge treatment is usually done in three main steps:

- The thickener also called first dewatering which is taking as input the grease and the sludge (primary sludge coming from the primary treatment and the secondary sludge coming from the biological treatment) and process them in order to generate the raw sludge.
- The digester which is using the stabilization (decrease or organic matter) technic to produce the biogas. It takes as input the raw sludge coming from the thickener generating in one side the biogas and in other side waste material. The temperature has an important effect on the physic-chemical properties of the components found in the digestion substrate. It also influences the growth rate and metabolism of micro-organisms and hence the population dynamics in the anaerobic reactor. An increasing temperature has several benefits including an increasing solubility of the organic compounds, enhanced biological and chemical reaction rates, and an increasing death rate of pathogens (thermophilic conditions). However, the application of high temperatures (thermophilic) has counteracting effects: there will be an increase of the fraction of free ammonia, which plays an inhibiting role for the microorganisms. It is important to maintain a stable operating temperature in the digester, since sharp and/or frequent fluctuations in temperature affect the bacteria, especially the methanogens (Lise Appels, 2008). A stable temperature around 35°C is generally used within the digesters.
- The thickener and storage tank also called final dewatering is taking the waste material coming from the digester to generate sludge disposal as landfill, incineration or agricultural usage. It is using centrifuge and mechanical press to process the remaining waste sludge.

2.2 Energy consumption on WWTP

A WWTP is a complex structure that requires a significant amount of energy. Within the WWTP there are: Buildings, equipment’s, laboratories. Each of them required energy to work. Buildings should be heated or cool down, there are also light and computers that are using energy.

Equipment's of the WWTP are also using energy. Anaerobic digestion requires some heating in order to keep the temperature around 36°C. Some equipment's of the WWTP are automated, this means a control station that is using electrical energy.
Overall, a WWTP energy consumption depends on the quantity of sewage sludge, the COD (chemical oxygen demand) removal and the nitrogen removal (Zhen, Zhi, & LiPing, 2019). An overview of the main consumption units has been provided by (Kolisch, Thomas, Inka, & Hansen, 2009) and is given here below:

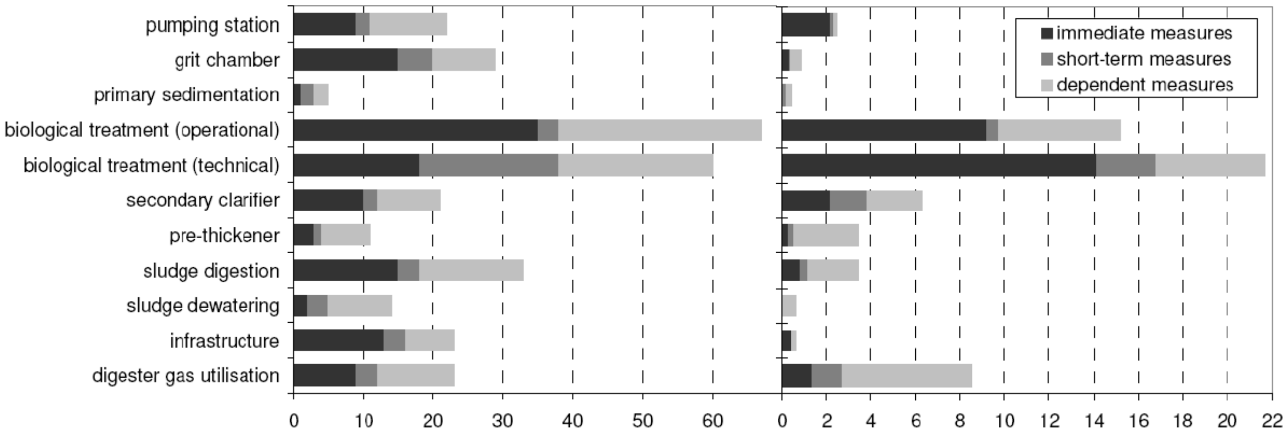


Figure 2: Overview of the main energy consumption units of WWTP

2.3 Energy production on WWTP

Energy production on WWTP comes mainly from the biogas production. It is sometimes possible to produce additional sustainable energy using solar panels per example. Below, we will mainly focus on the energy produced from the biogas.

2.3.1 Methanation technics

Methanation is the process that transform the processed sewage sludge into biogas, here below are described some main principles of the methanation process.

2.3.1.1 Principle of the methanation

Anaerobic digestion is a complex process which requires strict conditions in the absence of oxygen. The principle of anaerobic digestion is based on 4 succinct steps called biochemical step. These steps are delicate and require the intervention of certain bacteria. The different biochemical steps of anaerobic digestion are:

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

Below is summarized the different steps involved in the anaerobic digestion.

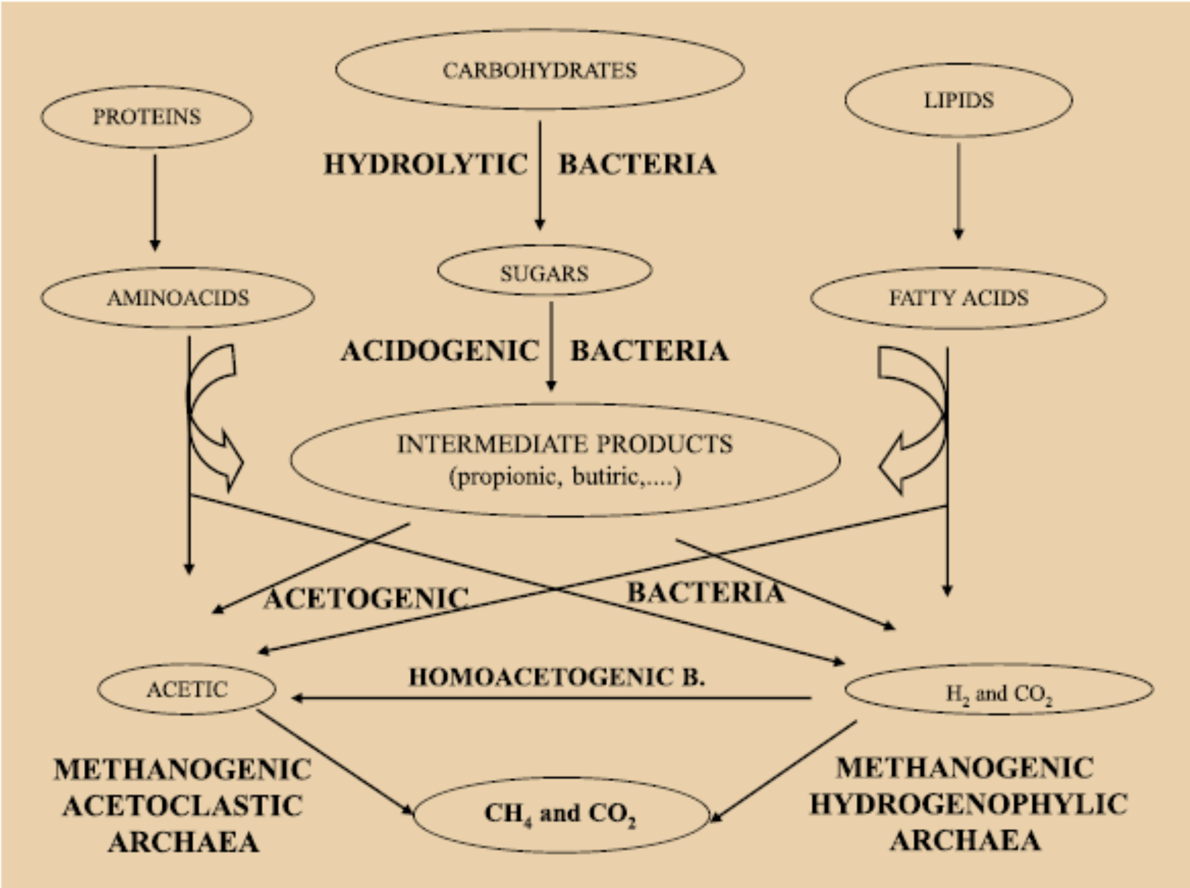


Figure 3: Different steps of the anaerobic digestion (Borja & Rincon, 2011)

2.3.1.2 Hydrolysis

This is the first reaction of methanization. it is a reaction which takes place in less than one hour in the presence of aerobic bacteria with a pH being between 4,5 and 6,3. During this step, monomers are obtained resulting from the degradation of organic macromolecules (Anukam, Mohammadi, Naqvi, & Granström, 2019). The complex organic structures of sewage sludge are usually broken by hydrolytic bacteria and released enzymes (Carrère, et al., 2010).

2.3.1.3 Acidogenesis

Acidogenesis is the second reaction of anaerobic digestion. During this step, with the help of the fermentation of monomers obtained from the hydrolysis reaction, organic acids and alcohols are obtained. The duration of this process is less than one hour in the presence of acidogenic bacteria. The pH during this phase remains the same as for the hydrolysis, between 4.5 and 6.3.

The reaction equations for this process are as follows (Anukam, Mohammadi, Naqvi, & Granström, 2019):

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \qquad \text{Eq. 1}$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \qquad \text{Eq. 2}$$

$$C_6H_{12}O_6 \leftrightarrow 3CH_3COOH \qquad \text{Eq. 3}$$

2.3.1.4 Acetogenesis

Acetogenesis is the third stage of methanation, also called the dehydrogenation stage. [10] It takes place in a digester and is the step preceding methanogenesis. With the help of acetogenic bacteria, organic acids and alcohols obtained from acidogenesis are transformed into acetic acids, carbon dioxide and hydrogen. This stage lasts between 1 and 4 days and the corresponding PH varies between 6.8 and 7.5.

The reaction equations taking place in this step are as follows:

$$CHCHCOO- +3HO \leftrightarrow CHCOO- +H+HCO- +3H \quad \textit{Eq. 4}$$

$$C_6H_{12}O_6 + 2H_20 \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad \textit{Eq. 5}$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO- +3H_2 + H \quad \textit{Eq. 6}$$

2.3.1.5 Methanogenesis

Methanogenesis is the fourth and final step in anaerobic digestion. During this step, bacteria called methanogens convert acetic acids into methane (CH_4) and carbon dioxide ($C0_2$) mainly. Methanogenesis lasts between 1 and 5 days and its pH remains between 6.8 and 7.5 as for the acetogenesis.

The percentage of methane (CH_4) obtained is between 45% and 70%, that of carbon dioxide ($C0_2$) is between 30% and 55% (KAPARAJU & RINTALA, 2013). Excepted these products there are also some remaining traces of:

- Hydrogen sulfide with a concentration between 0 and 2000 ppmv (parts per million volume)
- Ammonia with a concentration between 0 and 590 ppmv

The full composition of the biogas after the anaerobic digestion is given below ((KAPARAJU & RINTALA, 2013):

Parameter	Farm-scale AD plant	Centralised AD plant	Landfill	Sewage treatment plant	Natural gas
CH_4 (vol %)	55–60	60–70	35–65	60–65	81–89
Other hydrocarbons (vol %)	0	0	0	0	3.5–9.4
H_2 (vol %)	0	0	0–3	0	—
CO_2 (vol %)	35–40	30–40	25–45	35–40	0.67–1.00
N_2 (vol %)	<1–2	2–6	<1–17	<1–2	0.28–14.00
O_2 (vol %)	<1	0.5–1.6	<1–3	<0.05–0.70	0
H_2S (ppm)	25–30	0–2000	30–500	<0.5–6800	0–2.9
NH_3 (ppm)	≈100	≈100	≈5	<1–7	0
Halogenated compounds (mg/m^3)	<0.01	<0.25	0.3–225	0–2	—
Siloxanes (mg/m^3)	<0.03–<0.2	<0.08–<0.5	<0.3–36	<1–400	—
Wobbe index	24–33	24–33	20–25	25–30	44–55
Lower heating value (MJ/Nm^3)	19.7–21.5	21.5–25.1	10.7–23.3	21.5–23.3	31–40

2.3.2 Main parameters affecting the anaerobic digestion

Bacteria are not the only parameters that can influence the anaerobic digestion process even if they have a significant influence on the result of the anaerobic digestion. Other parameters whose absence could slow down or significantly impact the anaerobic digestion are:

- The temperature
- The pH
- The carbon to nitrogen (C/N) ratio

2.3.2.1 The temperature

Temperature plays a very important role in anaerobic digestion. Given that anaerobic digestion is a bacterial reaction, and that the temperature has a great influence on the bacterial reactions, it would therefore be obvious to affirm that the temperature is a necessary and main actor in that process (Impact of the temperature during the Biogas production, n.d.).

As the temperature in the digester increases, the speed of the reaction also increases. The temperature therefore influences the speed of the reaction. However, due to the diversity of bacteria present in the anaerobic digestion process, the increase of temperature is not a favorable ecosystem for all the bacteria. This is the main reason why the temperature during the anaerobic digestion should be controlled to ensure that the ecosystem remains favorable for the development and reproduction of these bacteria.

Depending on the temperature, there are 3 types of methanation that are explained below.

2.3.2.1.1 Psychrophilic methanation

For this type of methanation, the reaction takes place at ambient temperature generally between 5°C and 25°C; this means that the reactor is not using external heating.

This type of anaerobic digestion does not require input of energy to heat the digester and is therefore suitable for areas with moderate temperatures.

2.3.2.1.2 Mesophilic methanation

In this case of methanation, the digester is heated to a temperature between 35°C and 40°C. When the digester is heated to the highest temperature, the production of biogas increases without dehydration.

The mesophilic methanation is the most common type of digestion due to its stability over the time in term of methane production.

2.3.2.1.3 Thermophilic methanation

This type of anaerobic digestion is carried out at a temperature greater than or equal to 50°C. Due to its high temperature, the speed of the reaction increases, which accelerates the reaction and therefore reduces the digestion time of the sludge.

This type of anaerobic digestion is interesting from a hygienic aspect because, with the high temperatures of the digester, it allows the elimination of harmful pathogens resistant to mesophilic methanation.

Thermophilic anaerobic digestion does not only have positive aspects indeed, it is very energy consuming, unstable and therefore requires frequent control (Impact of the temperature during the Biogas production, n.d.).

2.3.2.2 The pH

The pH is an important parameter for the anaerobic digestion, indeed the bacteria impacting the anaerobic digestion are quite stable within a given pH range. It is a good indicator of disequilibrium during the anaerobic digestion process. Usually, when the pH is between 6 and 8 which is the neutral range, the biogas production speed increases. This means that there is a high correlation between the pH and biogas production speed. The carboxylic acids generated during the anaerobic digestion are reducing the pH in the digester (Boe, 2006).

2.3.2.3 The C/N ratio

The C/N ratio allows us to have an idea of the nutrient content of a substrate. For anaerobic digestion, the C/N ratio should neither be too high nor too low but should be the right level. If C/N is very low, the reaction can be slowed down or stopped because the amount of nitrogen is higher than necessary. If C/N is very high, the production of biogas will be lower because the quantity of nitrogen will be insufficient for the digester reaction. The judicious C/N ratio is between 20 and 30 (Borja & Rincon, 2011).

2.3.2.4 The methanation unit

Depending on the type of waste to be processed, there are several types of anaerobic digestion units (BASTIDE, 2015):

- On-farm anaerobic digestion units,
- Collective anaerobic digestion units (farm waste + other external waste),
- Centralized anaerobic digestion unit (concerns various wastes including agricultural waste),
- WWTP methanation unit (sludge from water purification stations),
- Anaerobic digestion unit for food industry
- Bio-waste methanation units (from selective collections),
- Methanation units for household waste,
- Anaerobic digestion unit for non-hazardous waste

In the next section, the focus will be on the anaerobic digestion of sewage sludge within the WWTP.

2.3.3 Different forms of digesters

Within WWTP, the existing technology is free sludge technology. Free sludge digesters differ from each other by their geometric shape (Agence de L'eau Rhone Mediterranée Corse, 2012).

There are 4 forms of digesters:

- Continental digesters type,
- Cylindrical digesters type,
- Ovoid digesters type,
- Anglo-American digesters type.

The most common digesters are cylindrical digesters type. Ovoid digesters are the most efficient ones. Ovoid digesters are most usually found in Germany (Reverdya, 2013).

2.3.4 Enhanced processes of the methanation

In order to improve the methanation process (quality and quantity of biogas produced), there are several applicable technics impacting either the primary treatment, the biological one or the digester itself. The next sections will present these different technics as well as the potential impact on the methanation process.

2.3.4.1 Enhancement on the primary treatment

Sludge primary treatments are treatments that sewage sludge undergo prior to anaerobic digestion. They can reduce the sewage sludge anaerobic digestion time and therefore save energy. Indeed, it has been shown above that for efficient anaerobic digestion, heating is required. There are 4 primary treatment methods that can help increasing the biogas production in WWTP, these methods are explained in the next sections.

2.3.4.1.1 Physical pre-treatment

There are several methods of physical treatment preceding anaerobic digestion. The different physical pre-treatment methods (Carrère, et al., 2010) are:

- Grinding: it is a technique which consists in reducing the size of the particles. This reduction of the particles size favors the disintegration of the sludge, consequently reducing the anaerobic digestion time of the sludge (Carrère, et al., 2010).
- Liquid shear: It depends on high liquid flows due to high pressure system allowing mechanical disruption to cells and flocs.
- Ultrasonic treatment: It is done with the goal to mechanically disrupt the cell structure and floc matrix.
- Lysis centrifuges: It operates directly on the thickened sludge stream in a dewatering centrifuge. After that process, it can re-suspend with the liquid stream.

More details on the physical pre-treatment and on their impact on the biogas production are provided in (Carrère, et al., 2010).

2.3.4.1.2 Thermal pre-treatment

It is usually done with a temperature between 160°C and 180°C. It consists on the degradation of the sludge gel structure. Thermal pre-treatment leads to partial solubilization of sludge, enhancing anaerobic digestion performances.

2.3.4.1.3 Biological pre-treatment

The biological pre-treatment is done before the anaerobic digestion. During that process, the hydrolysis before the anaerobic digestion is enhanced. The sludge pre-treatment lasts between 9h and 48h and is done with a temperature between 60°C and 70°C.

2.3.4.1.4 Chemical pre-treatment

The chemical pre-treatment separates greases, suspended solids and dissolved metals from a liquid water phase. This chemical process is achieved through pH adjustment and/or polymer treatment. This pre-treatment method pulls the impurities together so they become an insoluble particle that is heavier that the water with impurity falling out of the solution.

2.3.4.1.5 Combined pre-treatment

It is possible to combine different pre-treatment methods to enhance the sludge quality and the overall production of biogas. The effects of combined treatment has been analyzed here (Yi, Han, & Zhuo, 2013) and is showing the potential benefit in term of biogas production improvement that could be obtained when different pre-treatments methods are combined together.

2.3.4.2 Enhancement on the biological treatment

Biological treatment, through the aeration process, is the stage which consumes most energy in the treatment of wastewater, usually around 54.1% (Shen, L.Linville, Urgun-Demirtas, M.Mintz, & W.Snyder, 2015).

Optimizing biogas production implies reducing the energy required by the wastewater treatment process. In order to optimize this process, the energy consumed by the aeration must be reduced because this step consumes more than half of the energy of the overall process. The following could be done for the enhancement:

- Maintenance should be done on a regular basis by cleaning the aeration membranes once or twice a year
- Provide guidance systems and air intake in order to install during the design of the ventilation system other rackets as needed and be able to follow any increase in the capacity of the WWTP
- Automate the control of the aeration in order to reduce the oxygen requirement (CHAOUI GHALI , 2008).

2.3.4.3 Enhancement on the digester

In the digester, optimization of the biogas production can be done through the following process.

- co-digestion
- A/B process

We will discuss about these processes in the following sections.

2.3.4.3.1 Co-digestion `

Co-digestion in a WWTP is a process which consists in digesting the sludge in the presence of other products with a high methanogenic potential in order to increase the quality and quantity of the biogas.

The methanogenic capacity of some products that could be used for the co-digestion to enhance the biogas production are given within Figure 4.

Most of the time, the sludge co-digestion is associated with co-substrates (Ling Chow, et al., 2020) such as:

- the organic fraction of municipal solid waste,
- food waste,
- agricultural waste,
- crude glycerol and other oils, fats and grease.

In order to optimize the biogas production, the sludge co-digestion with a co-substrate must respect certain proportions which will lead them to the expected results in term of biogas production optimization. Indeed, In order to achieve the optimal carbon-to-nitrogen (C/N) ratio for anaerobic digestion, which is around 20–30, wastewater sludge with a low C/N ratio of 6–10 can be co-digested with the co-substrate with a higher C/N ratio to counterbalance the nutrients and avoid inhibition that leads to system instability (Ling Chow, et al., 2020).

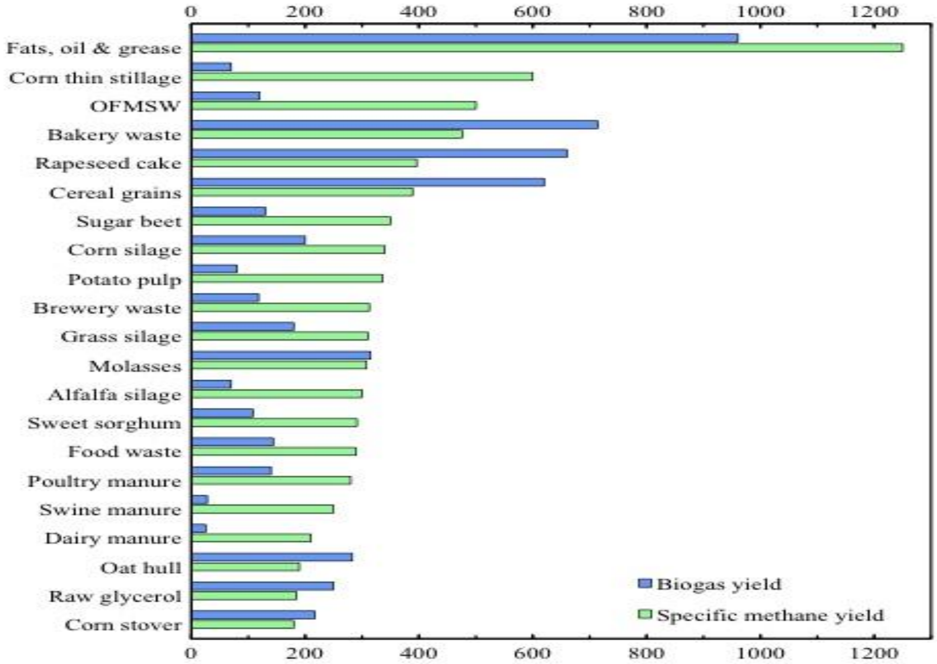


Figure 4: Methanogenic capacity of main product involved in the co-digestion process

2.3.4.3.2 A/B process

The A/B process (absorption-de-ammonification) was introduced in 1997 in Germany. The main purpose of the creation of this process was to keep WWTP that could not meet carbon emission standards.

This process takes place in the aeration tank in the presence of two activated sludge stages. Stage A allows the maximum carbon to be captured in quasi-oxygen neutrality with low aeration. Stage B enables the nitrogen treatment.

With this process, step A reduces the chemical oxygen demand by 70% which consequently reduces the energy demand of the biological treatment.

Nowadays, this method has been put aside because of the lack of control in the carbon capture within the step A.

2.3.5 Energy recovery from biogas description

The biogas produced by WWTP can be converted in different forms of energy depending on the biogas composition, its production, its quality and quantity. These points are driving not only the biogas storage, but also the energy recovery from the biogas.

The energy recovery from the biogas could be done in different methods:

- Heating production
- Electricity production
- Natural gas that could be used by households.
- Natural gas for vehicle
- Co-generation

2.3.5.1 Heating production

The heating production from the biogas is the simplest and less costly system in term of energy recovery from the biogas. The conversion from biogas to heating is done using an efficient boiler that does not require a big percentage of methane to produce the heating.

The heating produce by burning the biogas can mainly be used within the WWTP (heating of the rooms, heating of the water) to avoid losses due to transportation from the WWTP to another point (ALLAIN, MELFORT, & ALLO, 2018).

2.3.5.2 Cogeneration

The cogeneration is a process consisting of the production of two types of energy from a given plant. In our case, co-generation could be used to produce heating and electricity from the WWTP biogas. There are several technics that can be used for the cogeneration from the biogas:

- Cogeneration with a Sterling engine
- Cogeneration with a fuel cell
- Cogeneration with a steam turbine
- Three-way Cogeneration which can produce three different sorts of energy (heating, cold and electricity)
- Combined cycle cogeneration (using a steam turbine associated with a gas turbine).

2.4 Benchmark values for energy on WWTP

Several parameters are used to characterize a WWTP. Important ones that are relevant for the WWTP characteristics are the following:

- **Population equivalent** (PE) related to the WWTP. A WWTP is designed mainly with respect to its related PE size and the expected growth of that PE over the next decade.
- **Dry solid:** This is the amount of dry matter contained within the sewage sludge. It is usually given in g PE/day or g PE/year. This means grams PE per day or grams PE per year. It could also be given as a percentage of the raw sewage sludge.
- **Sewage Sludge Volume:** This is equivalent to the volume of raw sewage sludge processed by the WWTP. It can be given as an average value per day or per year either in cubic meter or in liters. Sometimes the sewage sludge volume is also given in liter PE per day (l PE/day).
- **WWTP energy consumption:** This is the overall energy consumption of the WWTP which is mainly used for heating and for electrical needs. The overall energy consumption of the WWTP could be given in MWh (per day or per year). It could also be given as an average with respect to the PE, in that case it is given in KWh/(PE * day).
- **Biogas production:** This is the volume of biogas produced by the WWTP. It could be given as an overall value of the biogas produced per year (or per day) in cubic meters. It can also be given as a volume per PE per day (l/PE/day) or as a volume per dry solid weight (l/kg of dry solid)
- **Energy production:** This is the energy produced by the WWTP from the Biogas. Depending of the type of energy recovery from Biogas, it could be either heating only

or a mixed between heating and electricity. In both cases, the energy produced can be given in MWh (per day or per year) It could also be estimated as an average of the energy produced per PE in Kwh (per day or per year).

- **Energy self-coverage:** This is the ratio between the WWTP overall energy produced with respect to the WWTP overall energy consumption. It shows how the WWTP is able to cover its requirements in energy with respect to the overall need of the WWTP. It is an average taken over the year as there is some seasonality on the energy usage between the winter (more heating request) and the summer.

The summary of the benchmark parameters and values is given here below (Kolisch, Thomas, Inka, & Hansen, 2009):

Parameters	Typical Values
Dry Solid	60-90 g PE/day
Total Energy Consumption	32 - 45 kWhel/(PE*a) for < 100,000 PE and 28 - 32 kWhel/(PE*a) for >100,000 PE.
Digester Heating Consumption	Between 13.5 kWhth/(PE*a) and 19.7 kWhth/(PE*a)
Biogas Produced	15-28 l/(PE*d) or 0,5-0,9m3/Kg of Dry Solid
Self Coverage of Heating	70%-100%
Self Coverage of Electricity	37%-68%

Table 1: Summary of the benchmark parameters and values

For the overall energy self-coverage, we do not have a clear value defined within the literature, however based on the self-coverage provided for both the heating and the electricity, it will be assumed here that the benchmark for overall energy self-coverage is between 55% and 85%.

The biogas composition in term of methane is usually between 60% and 70% and the CO_2 constitutes the rest of the biogas.

3 Energy consumption on Luxembourgish WWTP

3.1 Generalities

Within this section, Luxembourg WWTP where the biogas production is done are presented. The focus here is done for SIDEN WWTP, Mersch WWTP and Echternach WWTP. Those three WWTP are using anaerobic digestion for the biogas production.

3.2 Bleesbruck WWTP

The Bleesbruck WWTP is a plant managed by the SIDEN which is located in the north of Luxembourg between Diekirch and Bettendorf. The Bleesbruck station is a biological WWTP. The WWTP uses natural purification processes for the wastewater. The Bleesbruck WWTP was built in 1963 and has since undergone several upgrades, the most recent of which was done in 2019. This station was designed for 100,000 persons equivalent (PE) and will increase its capacity to 130,000 PE from 2021 to 2030. Information described here below are mainly taken from Bleesbruck booklet available here (SIDEN, 2012).

The Bleesbruck treatment plant has two treatment channels:

- the water treatment channel (primary treatment, biological treatment) •
- the sludge treatment channel (anaerobic digestion)

3.2.1 SIDEN description

The SIDEN (Syndicat Intercommunal de Dépollution des Eaux résiduaires du Nord) is an association of municipalities responsible of water treatment plant in the North of Luxembourg. There are 35 municipalities in the North of Luxembourg that are members of the SIDEN. Within these municipalities, there are 83688 people living there within an area of 1075 km^2. A complete description of SIDEN with its main responsibilities can be found here (SIDEN Website, n.d.).

Within the SIDEN, there are 331 wastewater collection plant, 92 mechanical wastewater treatment plant and 89 biological water treatment plant.

The main goal of SIDEN is taking care of the wastewater drainage and clean-up of its municipalities. This is achieved through the following tasks:

- Drainage and treatment of wastewater of its connected municipalities
- Taking care of the wastewater treatment plan and the ancillary associated structures
- Treatment and recovery of sewage sludge
- Acquire and taking care of the technical equipment.
- Invest on the required infrastructure in order to fulfill the needs of its municipalities.

Several sections are working together with each of them being responsible of different areas. The main sections of SIDEN are:

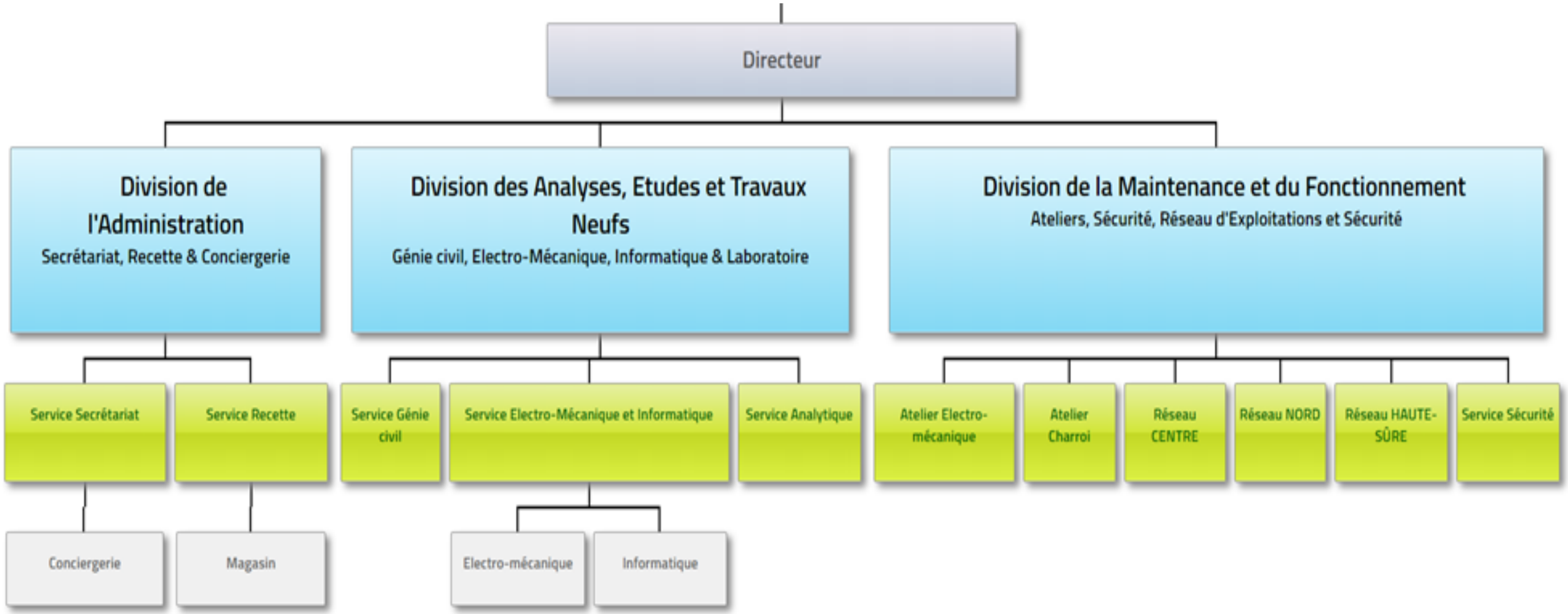
- The civil engineering section: That section is responsible to assist the other sections on identifying and elaborating solutions for the different issues linked to the civil engineering. It also ensures the inspection of the different pipes using special vehicles equipped with camera and the archives of the technical data of the different infrastructures. On top of that, the civil engineering section also takes care of the high-level geographical information system (GIS) allowing the different municipalities an access to the sewage network via Internet. The present master thesis has been done within the coordination and the supervision of the head of that section.

- The electro-mechanic and informatic section: This section has 2 main units. The electro-mechanic unit is responsible of the design and the maintenance of the low voltage command network and of the different measurement sensors used by the SIDEN. The informatic unit is responsible of the informatic infrastructure (hardware and software) and of the interconnexion of the different sites.
- The electro-mechanic factory section is responsible of the maintenance and reparation of the different infrastructure and equipment's. The factory is responsible to design and produce some of the items used for the maintenance and reparations.
- The analytical section: This section is responsible of ensuring that SIDEN remains with the ISO/CEI 17025 norm. It is responsible of doing wastewater analysis at the input and output of the wastewater treatment plant.
- The security section: This section is responsible of the health and security of the SIDEN employees.
- The financial section: This section is responsible of the expenses and incomes of the SIDEN.
- The concierge service section: This section is responsible of the concierge service related to the different buildings and infrastructure of the SIDEN.
- The cartage maintenance section: This section is responsible of the car maintenance of the SIDEN.
- The North, Center and Haute-Sure network section: this section is responsible of the three exploitation networks available within the SIDEN (with the North and the Haute-Sure ones).
  This section ensures the day-to-day maintenance of the various water evacuation and decontamination infrastructures, in particular storm weirs, pumping stations, storm basins, main collectors, mechanical & biological wastewater treatment plants and sludge treatment centers.
- The warehouse section: This section is linked to the finance section and is responsible of the purchase of the different equipment's used for the maintenance of the different infrastructure managed by the SIDEN.

The different services of SIDEN are working and collaborating for a smooth work. The different sections are integrated within three main departments:

The administrative department, the study and analysis department and the maintenance department. The complete organigram of the SIDEN is provided on the next page of the present report.

The present master thesis study has been done within the civil engineering section under the supervision of the head of that section.


Directeur
Division de l'Administration
Secrétariat, Recette & Conciergerie
Division des Analyses, Etudes et Travaux Neufs
Génie civil, Electro-Mécanique, Informatique & Laboratoire
Division de la Maintenance et du Fonctionnement
Ateliers, Sécurité, Réseau d'Exploitations et Sécurité
Service Secrétariat
Service Recette
Service Génie civil
Service Electro-Mécanique et Informatique
Service Analytique
Atelier Electro-mécanique
Atelier Charroi
Réseau CENTRE
Réseau NORD
Réseau HAUTE-SÛRE
Service Sécurité
Conciergerie
Magasin
Electro-mécanique
Informatique

3.2.2 Description of Bleesbruck plant

Bleesbruck WWTP is located in the North au Luxembourg close between Diekirch and Ettelbruck. Bleesbruck WWTP is actually designed for a population equivalent of 100000 PE. Below, are described the main components of that station from the sludge input to the biogas generation.

3.2.2.1 Water treatment channel

The water treatment system is based on the decontamination of wastewater. This process is carried out in many stages at the Bleesbruck WWTP:

- Primary treatment
- Biological treatment

Primary and biological treatments are done together before the sludge treatment.

3.2.2.1.1 Primary treatment

The primary treatment at the Bleesbruck station consists of the physical cleaning of the wastewater. This is done following several steps:

- **Coarse screening**: This is the first stage of the physical treatment; it consists of removing large particles greater than 15mm to avoid clogging at the pumping station.
- **Raw water lifting station**: As the incoming water located at a depth of 5m are flowing into a sump with a capacity of 140m^3, they are raised to 11m by 6 centrifugal pumping units (five of them with a capacity of 360m^3/hour and the last one with a capacity of 100m^3/hour). Later one, the processed water is discharged into the Sure.
- **Receiving installation for emptying machine**: It consists of receiving in the primary treatment process additional external sludge at WWTP as some debris. These external bodies will be sent to a special installation in the presence of sensors.
- **Filtering process**: it consists of filtering the remaining waste floating in the water through a thin grid filter of 6 mm.
- **Aerated sand trap, degreaser and oil separator**: This step involves the separation of oils and fats by flotation and the removal of sands and gravel. This process last around 16 minutes.
- **Intermediary decanters:** The mix of wastewater with activated sludge coming from the high load biological treatment is split to two intermediary circular decanters. Each of the decanter has a diameter of 22m and a depth of 1.9m which means a capacity of 740m^3 for each of the decanter. The sludge which are heavier than water are going to the bottom of the decanter and are extracted with 3 pumps at the rate of 350m^3 per hour. The remaining water are going to the surrounding area of the decanter and kept there during 2h and 20 min.
- **Analytical control container:** The wastewater coming from the intermediary decanter are continuously analyzed in order to measure some parameters as temperature, oxygen, nitrogen and phosphorus.

- **Secondary decanters:** The output of the low load biological treatment is sent to two conical secondary decanters. Each of them having a diameter of 12m, a depth of 10.5m with a capacity of 360m^3. The treatment lasts 1h15min within these decanters. The remaining sedimented sludges are pumped toward nitrification reactors at a rate of 300m^3 per hour while the processed water coming from these secondary decanters are flowed to the Sure.

Water analysis is done continuously during the primary treatment.

3.2.2.1.2 Biological treatment

The biological treatment in the Bleesbruck WWTP is done in two steps:

- High load biological treatment
- Low load biological treatment

3.2.2.1.2.1 High load biological treatment

The first step of the biological treatment is done using active sludge at high load with aerated tiny bubbles. The biological treatment is taking place within a rectangular basin which have a length of 30 m and a width of 14 m. The overall capacity of that basin is 1230m^3 within a close area which has a stale air performed with compost filter. Wastewater within the basin is mixed with liquid bacteria that are ingesting the pollution available within the wastewater.

These liquid bacteria require a lot of oxygen to breath which means a continuous input of air which is ensured by two compressors achieving a flow of 5000m^3 of air per hour. During the biological treatment, carbon pollution tends to disappear. The biological treatment lasts a little bit less than 2 hours. The additional air is extracted from the close area using two turbo fans having for each an extraction capacity of 7500m^3 of air per hour.

During the biological treatment, phosphorus is removed using co-precipitation.

3.2.2.1.2.2 Low load biological treatment

The second step of the biological treatment is done using active sludge at low load within two circular basins having a diameter of 20m and a depth of 1.8m with an overall capacity of 570m^3 for each of them. The goal of this second step is to remove nitrogen by nitrification. This step lasts a little bit less than 2 hours.

3.2.2.2 Sludge treatment

The main objective of sludge treatment is to produce the biogas and to process the remaining sludges and convert them either into compost that could be used by farmers or into biogas (this is done at Friedhaff plant) or incinerate them.

The sludge treatment at Bleesbruck WWTP is done in several stages summarized here below:

- **Recirculation and total clean-up:** The sludge kept into the intermediate and secondary decanters are permanently flow down via some pumps to the high and low load biological treatment.
- **Excess sludge homogenization**: Excess sludges from biological treatment are pumped and mixed into a silo storage with a capacity of $100m^3$. Homogenization is ensured through blending within the silo.
- **Flocculation and thickening**: The liquid sludges homogenized have a water content of 99%. They are thickened up to 94% of humidity. This is done adding an external chemical element (polyelectrolyte cationic) and the main consequence is a significant reduction of the sludge volume (around 80%).
- **Anaerobic mesophilic digestion**: The thickened sludges are pumped to two digesters with a capacity of $1000m^3$ each. In these digesters, the sludge will be processed under mesophilic conditions (temperature of 36°C) during 21 days and produce biogas (CO_2 and CH_4).

The current Bleesbruck WWTP receives $40000m^3$ of wastewater per day during rainy weather and $12000m^3$ per day during dry weather. Yearly, the quantity of wastewater received makes it possible to produce on average 2200 tons of dehydrated sludge and $500000m^3$ of biogas.

3.2.2.3 Bleesbruck Biogas: composition, usage and energetic yield

The biogas produced (around $1300m^3$ per day) is stored within a gasometer of $750m^3$. This biogas is later used for the heating of both, the WWTP buildings and the digesters.

3.2.2.3.1 Bleesbruck biogas composition

The composition of the Bleesbruck WWTP biogas varied. The quantity of methane present in the biogas produced at Bleesbruck is above average.

The composition of the biogas with the lowest percentage of methane is 61.6% and 34.3% of CO_2 while the composition of the biogas with the highest percentage of methane is 67.3% methane and 31.3% of CO_2. The average methane composition of Bleesbruck biogas is 64.45%, this is in line with the biogas composition benchmark.

3.2.2.3.2 Energy recovery of Bleesbruck biogas

The Bleesbruck wastewater treatment plant produces 1300 m3 of biogas per day, around 500000 m3 per year. This biogas is stored in a 750 m3 gasometer and must be recovered as heat. This heat is used by the digesters and WWTP buildings.

3.2.2.3.3 Bleesbruck biogas energy yield

Bleesbruck WWTP produces $500,000m^3$ of biogas on a yearly basis (that biogas is mainly used for the WWTP and consumes additionally 3 GWh of electrical energy to produce that biogas.

Based on the energy table conversion provided here (Biogaz Methanisation, 2020), it is possible to convert the biogas into thermal energy. The average percentage of methane in the Bleesbruck

WWTP biogas is 64.45%. It is also well known that the natural gas contains in average 94.9% of methane.

1 KWh is equivalent to 0.0949 m^3 of natural gas and is also equivalent to 0.1397m^3 of Bleesbruck biogas. We can therefore estimate the potential thermal energy production of the 500000m^3 of biogas to 3.6 GWh. The yield of the boiler is estimated at 98%. The Thermal energy production is therefore estimated to 3.528 GWh.

Based on the Bleesbruck WWTP datasheet provided in the Annex, the overall yearly electrical consumption is 3GWh. Adding the equivalent energy from Biogas evaluated at 3.528 GWh, this means that the overall energy request of the Bleesbruck WWTP is 6.528 GWh per year. The Biogas energy coverage is estimated at 3.528 GWh which represents 54.% of the Bleesbruck WWTP energy demand.

3.2.3 Bleesbruck WWTP Benchmarking values

Before the changes that will occur during the next months in 2021, Bleesbruck main parameters can be summarized as below:

Parameters	**Bleesbruck**
Waste Water Volume	12000 m^3 /d - 40000 m^3/d
Dry Solid	6 ton / d
Power Consumption	8,2 MWh / d
Biogas Produced	1370 m^3/d
Self Energy Coverage	54,00%

Table 2: Summary of Bleesbruck WWTP main parameters as of today

After the changes, it is expected that the main parameters of Bleesbruck will become as below:

Parameters	**Bleesbruck (after 2021 changes)**
Sludge volume	223 m^3 /d - 275 m^3/d
Dry Solid	70 g PE/d
Power Consumption	27034 KWh / d
Biogas Produced	2685 m3/d - 3000 m^3/d
Heat produced	13560 KWh/d
Electricity Produced	3885 KWh/d
Self Energy Coverage	64,53%

Table 3: Summary of Bleesbruck WWTP main parameters after 2021 changes

Compared to the benchmark, the dry solid before the changes are estimated for a PE of 100000 to 60 g PE/d while it is estimated at 70g PE/d after the changes. This is in line with the benchmark which is expecting a value between 60 g PE/d and 90 g PE/d.

The biogas production before the changes is evaluated to 1370m^3/d which means 13.7 l/PE*d. After the changes, the biogas production is expected to increase between 26.9l/PE*d to

34.6l/PE*d. Before the changes we were below the lower value of the benchmark and after the changes the plant will be within the benchmark

The total energy consumption for the plant before changes is 30 KWh/(PE*a); after the changes of 2021, it will move to 27 KWh/(PE*a). In both cases, the power consumption is very close to the lower value of the benchmark.

The energy self-coverage of the plant as of today is 54%. This is calculated taking into account the overall plant energy requirement. This is close to the lower value of the benchmark. After the changes, the overall energy self-coverage will move to 64.53%. In term of electricity coverage, after the changes, the plant will have a self-coverage of 40.5%, and for heating it will have a self-coverage of 88.33%. This is in line with the benchmark for electricity and heating coverage. This means that Bleesbruck WWTP will be within the benchmark, however, there will still be room of improvement in term of energy efficiency.

3.2.4 Analysis of current situation at Bleesbruck

Important changes are foreseen within the next months at Bleesbruck WWTP. The main changes occurring will impact the following module:

- The Digester: Actually, there are two digesters having each a capacity of 1000m^3 working is serie. With the changes planed during the next month, there will be an additional digester of 2500m^3. This will allow increasing the daily biogas production from 1300m^3 per day to a daily production between 2685m^3 and 3000m^3 when the WWTP will run at its fully capacity. The three digesters (the two previous ones and the additional one) will work in serie. The two old digesters will have some significant changes on the mechanical equipment's (new security systems adapted to the biogas production, more powerful sewage sludge mixer, new sensors used to evaluate the level of biogas produced).
- Co-generation: This will allow a different energy recovery of the biogas. Part of the biogas will be used directly for heating purposes and the remaining part will be sent to the co-generation system and will generate electricity in one side and heating in other side.
- Sludge Pumping station: New sludge pumping station for the sludge flow will be installed in order to provide the necessary flow sludge to the three digesters. Efficient system for the heat flow between the three digesters will also be installed.

This shows that the changes done will help the plant to become more efficient in term of energy generated from the biogas produced by the plant but will still have room for improvement.

3.3 Mersch WWTP

The Mersch WWTP is a plant managed by the SIDERO (Syndicat Inter Communal de Dépollution des Eaux Résiduaires de l'Ouest) which is geographically located in the west center of Luxembourg. The Mersch station is a biological WWTP like the Bleesbruck one.

Mersch WWTP was built in 1969 and has since undergone several upgrades, the most recent of which was done between 2010 and 2016. The last upgrades have been done considering a PE to 70000. Information described here below are mainly taken from SIDERO website available here (SIDERO Website, s.d.).

As Bleesbruck WWTP, Mersch treatment plant has two treatment channels:

- the water treatment channel (primary treatment, biological treatment) •
- the sludge treatment channel (anaerobic digestion)

3.3.1 SIDERO description

SIDERO is an association of municipalities responsible of water treatment plant in the center west of Luxembourg. There are 26 municipalities in Luxembourg that are members of the SIDERO. Within these municipalities, there are 80000 people living there.

The goals of SIDERO are like the one of SIDEN within the related municipalities.

3.3.2 Description of Mersch plant

Mersch WWTP is in the center west of Luxembourg. Mersch WWTP is quite similar to Bleesbruck WWTP before the changes planned during 2021. The main difference comes from the size of equipment's which are linked to the PE. The other major difference comes from the energy recovery of the biogas. Indeed, within the Mersch WWTP, there is already the co-generation that is used in order to transform part of the biogas energy into both heating energy and electrical energy.

Water treatment, biological treatment and sludge treatment done within the Mersch WWTP are quite like what is done within the Bleesbruck WWTP.

3.3.2.1 Mersch Biogas: composition, usage and energetic yield

The biogas produced by Mersch WWTP is estimated at 1027 m^3 per day. The biogas produced is either used for the heating (WWTP buildings and the digesters) or used for electrical purpose after the co-generation.

3.3.2.1.1 Mersch biogas composition

The composition of the Mersch WWTP biogas is 65% of methane and 35% of CO_2. This is in line with the biogas composition benchmark.

3.3.2.1.2 Energy recovery of Mersch biogas

The Mersch WWTP produce around 375000 m3 of biogas per year. Main part of the biogas is used as heating energy in order to fulfill the WWTP requirement in heating. Through the co-generation, part of the produced biogas is transformed into electrical energy and used within the station.

3.3.2.1.3 Mersch biogas energy yield

Mersch WWTP produces 375,000 m^3 of biogas on a yearly basis (that biogas is mainly used for the WWTP requirement in heating and partly for electrical purposes) and consumes additionally 1.9 GWh of electrical energy to produce that biogas and to process the water.

The overall WWTP requirement in energy per year is 1.9 GWh of electrical energy and 2.4 GWh of thermal energy. This means that the energy self-coverage of Mersch WWTP is 55.8%.

3.3.3 Mersch WWTP Benchmarking values

A summary of Mersch WWTP benchmark parameters is provided here below:

Parameters	Mersch
Waste Water Volume	15101 m^3 /d
Dry Solid	22 g PE/d
Energy Consumption	5,21 MWh / d
Biogas Produced	1027 m^3 /d
Self Energy Coverage	55,79%

Table 4: Summary of Mersch WWTP main parameters

The dry solid is 22g PE/d which is low compared to the benchmark. The energy consumption is 23.77 KWh/(PE*a) which is also lower compared to the benchmark. The biogas produced is 12.83l/(PE*d) which is not far off the benchmark limit. The energy self-coverage is 55.79%, this is within the benchmark. In term of energy efficiency, the plant seems to be well placed, however, there is still room to improve for the biogas production and the energy self-coverage.

3.3.4 Analysis of current situation at Mersch

As of today, there is no major changes foreseen within the Mersch WWTP. The energy self-coverage is similar to the one of Bleesbruck WWTP before the changes that are foreseen during 2021. This means that there are some doors open to improve the biogas production and also the energy self-coverage efficiency.

3.4 Echternach WWTP

Echternach WWTP is a plant managed by SIDEST (Syndicat Intercommunal de Dépollution des eaux résiduaires de l'Est) which is geographically located in the east center of Luxembourg. The Echternach station is a biological WWTP similar to the Mersch one.

Echternach WWTP was built in 1975 and has since undergone several upgrades, the most recent of which was done during 2012. The last upgrades have been done considering a PE to 36000. Information described here below are mainly taken from SIDEST website available here (SIDEST Web site, s.d.).

As Bleesbruck WWTP, Echternach treatment plant has two treatment channels:

- the water treatment channel (primary treatment, biological treatment) •
- the sludge treatment channel (anaerobic digestion)

3.4.1 SIDEST description

SIDERO is an association of municipalities responsible of water treatment plant in the center west of Luxembourg. There are 25 municipalities in Luxembourg that are members of the SIDERO. Within these municipalities, there are 36000 PE living there.

The goals of SIDEST are similar to the one of SIDEN within the related municipalities.

3.4.2 Description of Echternach plant

Echternach WWTP is located in the east center of Luxembourg. Echternach WWTP is quite similar to Bleesbruck WWTP before the changes planned during 2021. The main difference comes from the size of equipment's which are linked to the PE. The other major difference comes from the energy recovery of the biogas. Indeed, within the Echternach WWTP, there is already the co-generation that is used in order to transform part of the biogas energy into both heating energy and electrical energy.

Water treatment, biological treatment and sludge treatment done within the Echternach WWTP are quite similar to what is done within the Bleesbruck WWTP.

3.4.2.1 Echternach Biogas: composition, usage and energetic yield

The biogas produced by Echternach WWTP is estimated at 500 m^3 per day. The biogas produced is either used for the heating (WWTP buildings and the digesters) or used for electrical purpose after the co-generation.

3.4.2.1.1 Echternach biogas composition

The composition of the Mersch WWTP biogas is 65% of methane and 35% of CO_2. This is in line with the biogas composition benchmark.

3.4.2.1.2 Energy recovery of Echternach biogas

The Echternach WWTP produce around 185000 m3 of biogas per year. Main part of the biogas is used as heating energy in order to fulfill the WWTP requirement in heating. Through the co-generation, part of the produced biogas is transformed into electrical energy and used within the station.

3.4.2.1.3 Echternach biogas energy yield

Echternach WWTP produces 185,000 m^3 of biogas on a yearly basis (that biogas is mainly used for the WWTP requirement in heating and partly for electrical purposes) and consumes additionally 1.26 GWh of electrical energy to produce that biogas and to process the water.

The overall WWTP requirement in energy per year is 2.45 GWh. Echternach energy production is estimated at 1.18 GWh. This means that the energy self-coverage of Mersch WWTP is 48.4%.

3.4.3 Echternach WWTP Benchmarking values

A summary of Echternach WWTP benchmark parameters is provided here below:

Parameters	Echternach
Waste Water Volume	5500 m^3 /d
Dry Solid	79 g PE/d
Energy Consumption	6,71 MWh / d
Electrical Production	1,15 MWh/d
Heat Production	2,1 MWh / d
Biogas Produced	3,25 MWh/d
Self Energy Coverage	48,40%

Table 5: Summary of Echternach WWTP main parameters

The dry solid of Echternach plan is 79 g PE/d, this is within the Benchmark level. The biogas production is estimated at 14.08l/(PE*d), this is a bit below the benchmark but quite close of the lower value of 15l/(PE*d). The energy consumption is estimated at 35 KWh/(PE*a), this is in line with the benchmark for the size of the plant in term of PE. The electric self-coverage is estimated at 24.95% which is below the benchmark but could be explained by the low size of the WWTP in term of PE. The heating self-coverage is estimated at 72.4%, which is in line with the benchmark. The overall self-energy coverage is estimated at 48.4% which is lower than the benchmark. This is not surprising as the Echternach plant is a small one in term of PE.

3.4.4 Analysis of current situation at Echternach

As of today, there is no major change foreseen within the Echternach WWTP. The energy self-coverage is similar to Mersch and Bleesbruck WWTP (before the changes that are foreseen during 2021 for that last one). This means that there are some doors open to improve the biogas production and also the energy self-coverage efficiency.

4 Optimization of energy situation on 3 Luxembourgish WWTP

The optimization of the energy situation of WWTP can be done at different steps of the WWTP from the water treatment to the sludge treatment. Before taking a decision of using a process to enhance the biogas production, it is important to analyze the adequation between the sludge composition, the pre-selected method as well as the energy efficiency. Indeed, it is obvious that if a given method can be used to enhance the biogas production, that method will necessarily increase the overall energy requirement of the WWTP. It is therefore important to also evaluate the overall energy efficiency taking into account the additional requirement of energy and the expected increase of biogas production.

Based on the structure of the Luxembourgish WWTP, the co-digestion appears to be one important and feasible method that could be used to enhance the biogas production. Indeed, the co-digestion can be done adding grease trap sludge (GS) obtained during the primary treatment. These greases can be mixed with the waste coming from Luxembourgish slaughterhouses.

That solution could be interesting when looking circular economy. Indeed, instead of using additional energy to clean and eliminate the waste coming from slaughterhouses, they could be used in the co-digestion to exploit their fat content. The potential enhancement of biogas production using the co-digestion has been discussed in (Davidsson, Lovstedt, La Cour Jansen, Gruvberger, & Aspegren, 2008). Within that article it has been shown that the biogas production can be significantly increased as shown in the table below:

Primary Substrate	Co-Substrate	Mixing Ratio	Improvment	Improvment assumed	Variation of CH4 Quality	Overall Improvment
Sewage Sludge	GS	05 -- 95	7%	5%	-3%	2%
Sewage Sludge	GS	10 -- 90	30%	25%	-3%	22%
Sewage Sludge	GS	25 - 75	45%	35%	-3%	32%
Sewage Sludge	GS	60 - 40	78%	60%	-3%	57%

Table 6: Increase of the biogas production using co-digestion of grease trap sludge.

The improvement is the theoretical value provided within the study made by (Davidsson, Lovstedt, La Cour Jansen, Gruvberger, & Aspegren, 2008). It is assumed that the theoretical improvement percentage will decrease a little bit when applying the co-digestion. With a mixing ratio of 10 – 90 (10% of grease trap sludge and 90% of sewage sludge), it is already possible to increase the energy production of biogas by 22%.

Another co-digestion method consists of adding the sterilized mass of slaughterhouse (SM) to the sewage sludge during the digestion process. This method has been discussed by (Pitk, Kaparaju, Palatsi, Affes, & Vilu, 2013) and the potential biogas energy enhancement are summarized below:

Primary Substrate	Co-Substrate	Mixing Ratio	Improvment	Improvment assumed	Variation of CH4 Quality	Overall Improvment
Sewage Sludge	SM	2,5 - 97,5	70%	50%	-3%	47%
Sewage Sludge	SM	05 95	165%	100%	-3%	97%
Sewage Sludge	SM	07,5 - 92,5	163%	100%	-3%	97%
Sewage Sludge	SM	10 90	136%	100%	-3%	97%

Table 7: Increase of the biogas production using co-digestion of sterilized mass of slaughterhouse.

With a mixing ratio of 2.5%-97.5% (2.5% of SM and 97.5% of sewage sludge) within the digester, one could expect to increase the biogas energy production by 47%. This solution is feasible as there are several slaughterhouses in Luxembourg and their waste could be used for co-digestion. However, this will generate a high/very high concentrated rejecting water, which has to be treated again in the activated sludge tank and would require additional energy for the aeration due to additional oxygen consumption. Using the study done within (Nowak, 2003), it is assumed here that the additional energy required for the aeration is equivalent to **0.8 KWh/m^3** of biogas.

The co-digestion using the organic fraction of municipal solid waste (OFMSW) has been studied by (Al-Addous, N. Saidan, Bdour, & Alnaief, 2019). They have shown that for certain co-digestion mixing ratios, the improvement in term of biogas production could become significant. The results of their study is summarized below in term of biogas production improvement:

Primary Substrate	Co-Substrate	Mixing Ratio	Improvment	Improvment assumed	Variation of CH4 Quality	Overall Improvment
Sewage Sludge	OFMSW	20 - 80	8%	5%	-7%	-2%
Sewage Sludge	OFMSW	30 - 70	39%	30%	-8,33%	22%
Sewage Sludge	OFMSW	40 - 60	93%	75%	-7%	68%

Table 8: Increase of the biogas production using co-digestion of the organic fraction of municipal solid waste

A mixing ratio of 30%-70% (30% of OFMSW and 70% of sewage sludge) could already improve the biogas energy production by 22%.

Co-digestion is preferred because it would not require additional equipment within the WWTP nor additional substantial requirement in terms of energy as would be the case if doing some additional treatments of water or of sludge.

Pre-treatment could also be used to improve the overall energy efficiency by increasing the biogas production. Evaluation of different pre-treatment methods have been discussed in (NDOH ROSSIER, MEMBREZ, & MOTTET, 2007). The authors showed in that article the expected biogas production improvement as well as the additional energy consumption required for some of the different pre-treatment methods they have studied. Here below is a summary of the main results taken for three pre-treatments methods that have shown having a potential good increase on the biogas production.

Pre-Treament Type	Technology	Dry Solid Mass	Sewage Sludge Reduction after digestion	Biogas Improvment	Improvment assumed	Additional Energy Requirement	Overall Improvment	Additional Cost
Physical	Ultrasonic Homogenizer	15%	14% - 18%	11% -33%	20%	3,7%	16,3%	9500€/y
	Lysis centrifuges	57%	18%	15%-30%	20%	0,75 - 1,1 KWh/m^3	N/A	18000€ - 85000€ + 6000€ - 10500€/y
Thermal	High Thermal Hydrolysis	30%	N/A	20% - 25%	22%	18%	4%	2.300.000 €

Table 9: Main results on biogas production obtained with different pre-treatment methods

4.1 Bleesbruck WWTP energy optimisation

Within this section, it will be assumed that the different enhancement methods described previously are applied to the Bleesbruck WWTP. Here the Bleesbruck plant is the one after the changes that will occur during 2021.

4.1.1 Description of the changes

The main changes that will occur within the Bleesbruck WWTP have been described in the section 3.2.4. These changes will mainly be done on the digesters (additional one with a capacity of 2500m^3) and on the biogas energy recovery (co-generation system will be added in order to convert part of the biogas produced into heating and electricity).

4.1.2 Energy consumption after the changes

After the changes foreseen during 2021 in the Bleesbruck WWTP, it is expected that the overall energy consumption will increase from **6.528** GWh to **9.867** GWh on a yearly basis. This represents an increase of 51%. In the meanwhile, the plant changes have been done assuming that the PE will increase from 100000 PE to 130000 PE, this represents an increase of 30%. It is important to highlight that most of the energy requirement increase will be covered by the additional biogas produced after the changes. The additional electrical power consumption is expected to increase from **3GWh** to **3.5GWh** per year.

4.1.3 Optimisation proposed after the changes

Within this section, we will analyze the impact of the pre-treatment and co-digestion methods on the Bleesbruck WWTP. It will be assumed that the potential gain on biogas production estimated for these enhancement methods will be obtained on Bleesbruck WWTP.

4.1.4 Energy efficiency after optimization

Optimization used here will be either co-digestion or pre-treatment method. We will analyse each of the two cases.

4.1.4.1 Co-digestion methods

The three methods evaluated are co-digestion with GS, SM and OFMSW.

In the case of GS, it is assumed that a mixing ratio of 10-90 (10% of GS mixed with 90% of sewage sludge) is achieved with the sludge grease traps. The co-digestion in that case does not require a significant increase of energy consumption, nor additional significant operating cost. The volume of energy generated from the biogas is expected to increase by **22%.**

The energy self-coverage when adding GS to the sewage sludge will increase from **64.53**% to **78.72**%. This means that the energy self-coverage of the plant will remain within the benchmark.

In the case of SM, it is shown in the Table 7 that a mixing ratio of 2.5% of SM added with sewage sludge could increase the biogas production by **47%.** The co-digestion in that case requires additional energy consumption for the aeration mainly estimated at **0.8 KWh/m^3** of biogas but, does not require additional significant operating cost as the SM are already available in Luxembourg close to the Bleesbruck plant and will need to be cleaned in any case.

The energy self-coverage when adding SM to the sewage sludge will increase from **64.53**% to **83.9**%. In that case the plant will significantly reduce the additional energy requirement from its own production of energy from the biogas while remaining within the benchmark.

Regarding OFMSW, it is shown in the Table 8 that a mixing ratio of 30% of OFMSW added with 70% of sewage sludge in the digester, could increase the biogas production by **22%** already. Acquiring OFMSW in a mixing ratio of 30%-70% could be a challenge when considering only the related PE of SIDEN municipalities. It is likely in that case that additional operating cost would be added in order to be able to get sufficient OFMSW. The energy self-coverage when adding OFMSW to the sewage sludge will increase from **64.53**% to **78.72**%. The plant will remain within the benchmark for the self-energy coverage.

4.1.4.2 Pre-treatment methods

Within the enhancement methods analyzed, considerations have been given to ultrasonic homogenizer, lysis centrifuges and high thermal hydrolysis methods.

Table 9 summarizes the potential enhancement in term of biogas production of each of these methods. For some of them, we have associated the additional energy requirement related to the pre-treatment method.

In the case of **ultrasonic homogenizer**, one can expect an overall biogas production increasing by 16.3% with additional expenses of **9500€** per year for the maintenance of the ultrasonic homogenizer. With an expected production of 3000m^3 of biogas per day, this will result to an increase of biogas production of **1.037 GWh** per year (it is assumed that the co-generation ratio between heating and electricity will remain the same). Assuming an electricity price of 0.12€/KWh, the additional biogas produced per year has a potential cost saving of **124547€** which is more than 13 times the maintenance cost. This showed that in term of energy efficiency this solution will allow increasing the energy self-coverage of Bleesbruck WWTP.

The energy self-coverage when using ultrasonic homogenizer as pre-treatment will increase from **64.53**% to **75.05**%. This shows the improvement in terms of energy efficiency of the plant. The plant will remain within the benchmark for the energy self-coverage.

*For **Lysis centrifuges**, if one can expect an overall biogas production increasing by 20%, this is done with additional energy requirement of Lysis centrifuges of 0.95 KWh/m^3 (we take a value above the average consumption provided in*

Table 9). The assumption is that the WWTP will produce 3000m^3 of biogas per day. If the production increases by 20%, this means a daily additional energy requirement of 3420 KWh due to the Lysis centrifuges. The energy produces by the additional 20% of biogas represents **3489 KWh** in a daily basis (it is assumed that the co-generation ratio between heating and electricity will remain the same). In term of energy, this represents a surplus of **25.18 MWh** taking the net increase between additional production and the energy consumption of the Lysis centrifuges. The potential cost saving of this surplus of energy is evaluated to **3022€** per year.

Taking an initial investment of 60000€ associated with a yearly maintenance cost of 9000€ and a discount cash flow rate of 5%, it is not worth investing on such a project as the maintenance cost are higher than the potential cost saving due to the Lysis centrifuges. **It is therefore not recommended to use the Lysis centrifuges for Bleesbruck WWTP.**

Regarding **high thermal hydrolysis** pre-treatment, the overall net biogas production will increase by 4%. This surplus of energy produced represents a potential yearly cost saving of **30563€**. The project to install the high thermal hydrolysis will require an investment of €2.3 Mio. Assuming a discount cash flow of 5%, the net cash flow after 20 years is **€-1.8Mio**.

This shows that after 20 years, the project investment cost will still be much higher than the income that the surplus of biogas generated thanks to the high thermal hydrolysis will bring. **It is therefore not recommended to invest on such project for energy efficiency purposes.**

4.1.4.3 Summary of energy optimization for Bleesbruck WWTP

For Bleesbruck WWTP, an analysis for the energy optimization has been performed taking into consideration not only the potential benefit in terms of additional biogas production, but also the economic viability in terms of project return on investment.

In the case of co-digestion, it appears that there will be no significant investment required as the co-substrates considered already exist and would be available in Luxembourg.

For the pre-treatment methods analyzed, they all required investment (initial investment and/or yearly maintenance costs).

The co-digestion methods analyzed will allow significantly increasing the biogas production and the energy self-coverage of Bleesbruck plant from 64.53% to 78.72% (for OFMSW and GS) and to 83.9% for SM.

For the pre-treatment methods analyzed, Lysis centrifuges and high thermal hydrolysis are not appropriated for energy efficiency purposes considering the investment cost required. Only the ultrasonic homogenizer is good not only for energy efficiency purposes, as it would allow increasing the energy self-coverage from 64.53% to 75.05%, but also in term of projects costs as it would allow covering the project cost (yearly maintenance cost) from the first year.

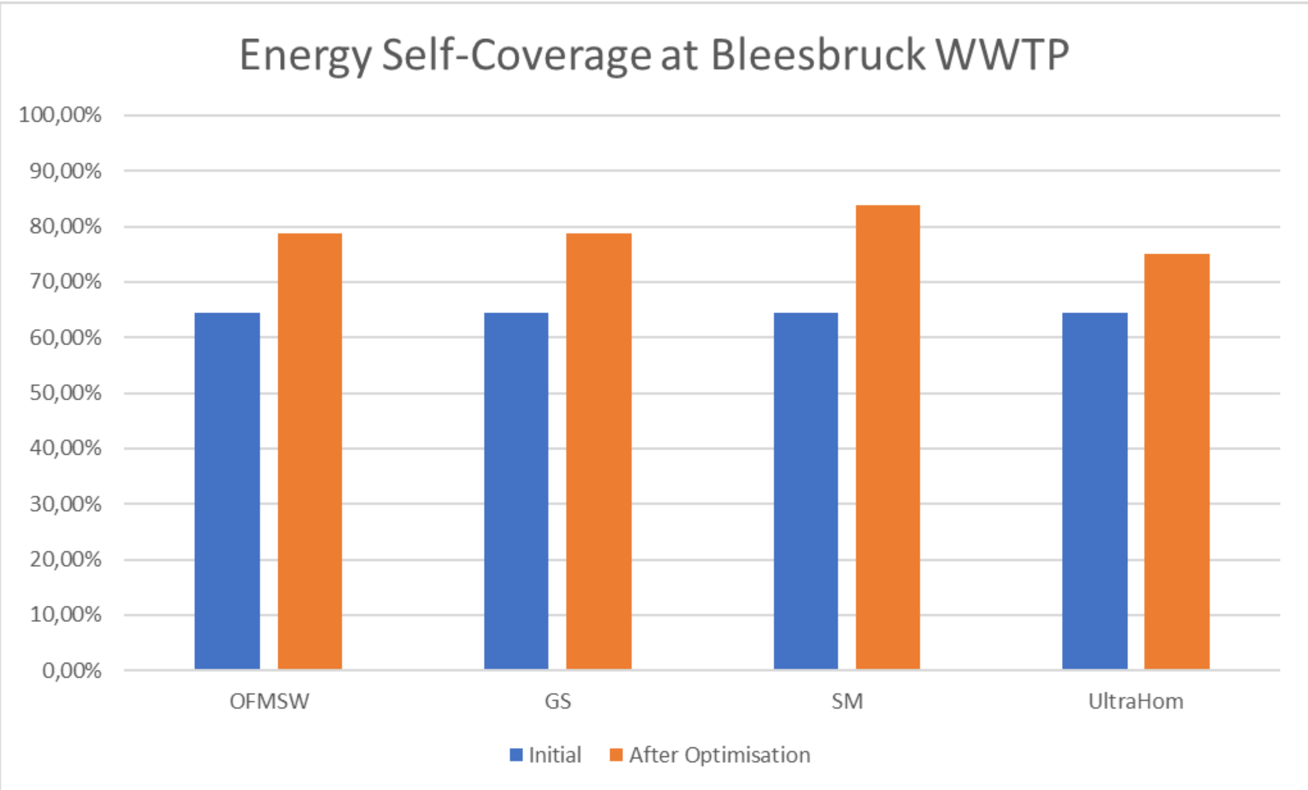


Figure 5: Energy self-coverage after optimization for Bleesbruck WWTP

The **Erreur ! Source du renvoi introuvable.**Figure 5 above summarized the improvement in term of energy self-coverage of Bleesbruck WWTP. UltraHom in that figure stands for Ultrasonic Homogenizer.

4.2 Mersch WWTP Energy optimisation

Within this section, it will be assumed that the different enhancement methods described previously are applied to the Mersch WWTP.

4.2.1 Optimisation proposed.

Within this section, we will analyze the impact of the pre-treatment and co-digestion methods on the Mersch WWTP. It will be assumed that the potential gain on biogas production estimated for these enhancement methods will be obtained on Mersch WWTP.

4.2.2 Energy efficiency after optimization

Optimization used here will be either co-digestion or pre-treatment method. We will analyse each of the two cases.

4.2.2.1 Co-digestion methods

The three methods evaluated are co-digestion with GS, SM and OFMSW.

In the case of GS, it is assumed that a mixing ratio of 10-90 (10% of GS mixed with 90% of sewage sludge) is achieved with the sludge grease traps. The co-digestion in that case does not require a significant increase of energy consumption, nor additional significant operating cost. The volume of energy generated from the biogas is expected to increase by **22%.**

The energy self-coverage when adding GS to the sewage sludge will increase from **55.79**% to **68**%.

In the case of SM, it is shown in the Table 7 that a mixing ratio of 2.5% of SM added with sewage sludge could increase the biogas production by **47%.** The co-digestion in that case requires additional energy consumption for the aeration mainly estimated at **0.8 KWh/m^3** of biogas but, does not require additional significant operating cost as the SM are already available in Luxembourg close to the Mersch plant and will need to be cleaned in any case.

The energy self-coverage when adding SM to the sewage sludge will increase from **55.79**% to **74.39**%.

Regarding OFMSW, it is shown in the Table 8 that a mixing ratio of 30% of OFMSW added with 70% of sewage sludge in the digester, could increase the biogas production by **22%** already. Acquiring OFMSW in a mixing ratio of 30%-70% could be a challenge when considering only the related PE of SIDERO municipalities. It is likely in that case that additional operating cost would be needed in order to be able to get sufficient OFMSW.

The energy self-coverage when adding OFMSW to the sewage sludge will increase from **55.79**% to **68**%.

4.2.2.2 Pre-treatment methods

Within the enhancement methods analyzed, considerations have been given to ultrasonic homogenizer, lysis centrifuges and high thermal hydrolysis methods.

The

Table 9 summarizes the potential enhancement in term of biogas production of each of these methods. For some of them, we have associated the additional energy requirement related to the pre-treatment method.

In the case of **ultrasonic homogenizer**, one can expect an overall biogas production increasing by 16.3% with additional expenses of **9500€** per year for the maintenance of the ultrasonic homogenizer. With an expected production of 1027m^3 of biogas per day, this will result to an increase of biogas energy production of **0.355 GWh** per year. Assuming an electricity price of 0.12€/KWh, the additional biogas produced per year has a potential cost saving of **42655€** which is almost 4.5 times the maintenance cost. This showed that in term of energy efficiency this solution will allow increasing the energy self-coverage of Mersch WWTP.

The energy self-coverage when using ultrasonic homogenizer as pre-treatment will increase from **55.79**% to **64.06**%.

*For **Lysis centrifuges**, if one can expect an overall biogas production increasing by 20%, this is done with additional energy requirement of Lysis centrifuges of 0.95 KWh/m^3 (we take a value above the average consumption provided in*

Table 9). The assumption is that the WWTP will continue producing 1027m^3 of biogas per day. If the production increases by 20%, this means a daily additional energy requirement of 1171 KWh due to the Lysis centrifuges. The daily additional energy produced thanks to the Lysis centrifuges is evaluated at 1194 KWh . In term of energy, this represents a surplus of **8.6 MWh** due to the introduction of the Lysis centrifuges as pre-treatment method per year. The potential cost saving of this surplus of energy is evaluated to **1035 €** per year.

Taking an initial investment of 60000€ associated with a yearly maintenance cost of 9000€, the additional cost saving of 1035€ due to the surplus of energy generated thanks to the Lysis centrifuges will not be enough to cover the maintenance cost. **This means that it is not wise in term of energy investing on such project for the Mersch WWTP.**

Regarding **high thermal hydrolysis** pre-treatment, the overall net biogas production will increase by 4%. This surplus of energy produced represents a potential yearly cost saving of **10468€**. The project to install the high thermal hydrolysis will require an investment of €2.3 Mio. Assuming a discount cash flow of 5%, the net cash flow after 20 years is €-2Mio.

This shows that after 20 years, the project investment cost will still be much higher than the income that the surplus of biogas generated thanks to the high thermal hydrolysis will bring. **It is therefore not recommended to invest on such project not only for energy efficiency purposes but also for project cost purposes at Mersch WWTP.**

4.2.2.3 Summary of energy optimization for Mersch WWTP

For the Mersch WWTP, an analysis for the energy optimization has been performed taking into consideration not only the potential benefit in terms of additional biogas production, but also the economic viability in terms of project return on investment.

In the case of co-digestion, it appears that there will be no significant investment required as the co-substrates considered already exist and would be available in Luxembourg.

For the pre-treatment methods analyzed, they all required investment (initial investment and/or yearly maintenance costs).

The co-digestion methods analyzed will allow significantly increasing the biogas production and the energy self-coverage of Mersch plant from 55.79% to 68% (for OFMSW and GS) and to 74.39% for SM. In the three cases, the self-energy coverage is improved and remain within the benchmark range.

For the pre-treatment methods analyzed, Lysis centrifuges and high thermal hydrolysis are not appropriated for energy efficiency purposes considering the investment cost required. Only the ultrasonic homogenizer is good not only for energy efficiency purposes, as it would allow increasing the energy self-coverage from 55.79% to 64.06%, but also in term of projects costs as it would allow covering the project cost (yearly maintenance cost) from the first year.

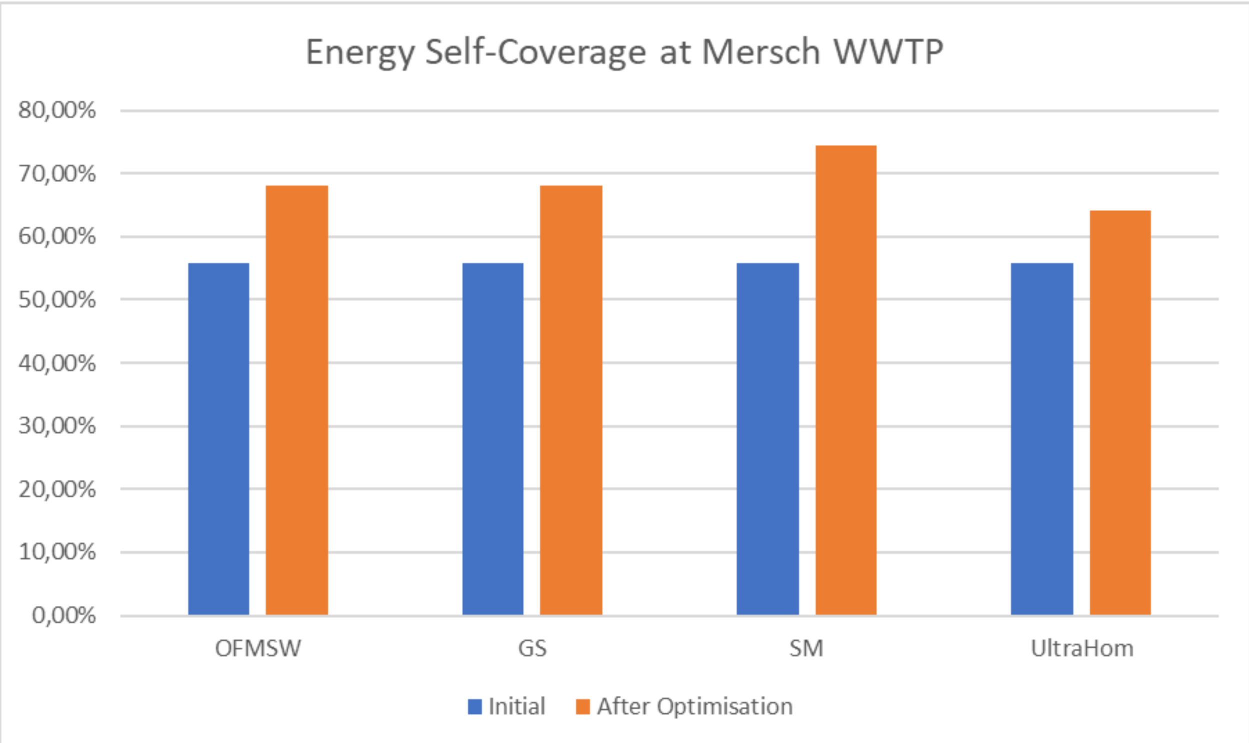


Figure 6: Energy self-coverage after optimization for Mersch WWTP

The Figure 6 above summarized the improvement in term of energy self-coverage of Mersch WWTP. UltraHom in that figure stands for Ultrasonic Homogenizer.

4.3 Echternach WWTP Energy optimisation

Within this section, it will be assumed that the different enhancement methods described previously are applied to the Echternach WWTP.

4.3.1 Optimisation proposed.

Within this section, we will analyze the impact of the pre-treatment and co-digestion methods on the Echternach WWTP. It will be assumed that the potential gain on biogas production estimated for these enhancement methods will be obtained on Echternach WWTP.

4.3.2 Energy efficiency after optimization

Optimization used here will be either co-digestion or pre-treatment method. We will analyze each of the two cases.

4.3.2.1 Co-digestion methods

The three methods evaluated are co-digestion with GS, SM and OFMSW.

In the case of GS, it is assumed that a mixing ratio of 10-90 (10% of GS mixed with 90% of sewage sludge) is achieved with the sludge grease traps. The co-digestion in that case does not require a significant increase of energy consumption, nor additional significant operating cost. The volume of energy generated from the biogas is expected to increase by **22%.**

The energy self-coverage when adding GS to the sewage sludge will increase from **48.40**% to **59**%.

In the case of SM, it is shown in the Table 7 that a mixing ratio of 2.5% of SM added with sewage sludge could increase the biogas production by **47%.** The co-digestion in that case requires additional energy consumption for the aeration mainly estimated at **0.8 KWh/m^3** of biogas but, does not require additional significant operating cost as the SM are already available in Luxembourg close to the Mersch plant and will need to be cleaned in any case.

The energy self-coverage when adding SM to the sewage sludge will increase from **48.40**% to **64.85**%.

Regarding OFMSW, it is shown in the Table 8 that a mixing ratio of 30% of OFMSW added with 70% of sewage sludge in the digester, could increase the biogas production by **22%** already. Acquiring OFMSW in a mixing ratio of 30%-70% could be a challenge when considering only the related PE of SIDEST municipalities. It is likely in that case that additional operating cost would be needed in order to be able to get sufficient OFMSW.

The energy self-coverage when adding OFMSW to the sewage sludge will increase from **48.40**% to **59**%.

4.3.2.2 Pre-treatment methods

Within the enhancement methods analyzed, considerations have been given to ultrasonic homogenizer, lysis centrifuges and high thermal hydrolysis methods.

Table 9 summarizes the potential enhancement in term of biogas production of each of these methods. For some of them, we have associated the additional energy requirement related to the pre-treatment method.

In the case of **ultrasonic homogenizer**, one can expect an overall biogas production increasing by 16.3% with additional expenses of **9500€** per year for the maintenance of the ultrasonic homogenizer. With an expected daily production of 559m^3 of biogas, this will result to an increase of biogas energy production of **0.193 GWh** per year. Assuming an electricity price of 0.12€/KWh, the additional biogas produced per year has a potential cost saving of **23203€** which is more than 2.4 times the maintenance cost. This showed that in term of energy efficiency this solution will allow increasing the energy self-coverage of Echternach WWTP.

The energy self-coverage when using ultrasonic homogenizer as pre-treatment will increase from **48.40**% to **56.33**%.

*For **Lysis centrifuges**, if one can expect an overall biogas production increasing by 20%, this is done with additional energy requirement of Lysis centrifuges of 0.95 KWh/m^3 (we take a value above the average consumption provided in*

Table 9). The assumption is that the WWTP will continue producing 559m^3 of biogas per day. If the production increases by 20%, this means a daily additional energy requirement of 637 KWh due to the Lysis centrifuges. The daily energy produces by the additional 20% of biogas represents 650 KWh. In term of net energy, this represents a surplus of **4.69 MWh** due to the introduction of the Lysis centrifuges as pre-treatment method per year, which is insignificant for energy efficiency purpose. The potential cost saving of this surplus of energy is evaluated to **563€** per year, which is insignificant.

Taking an initial investment of 60000€ associated with a yearly maintenance cost of 9000€, the additional cost saving of **563€** due to the surplus of energy generated thanks to the Lysis centrifuges will not be enough to cover the maintenance cost. **This means that it is not wise in term of energy investing on such project for the Echternach WWTP.**

Regarding **high thermal hydrolysis** pre-treatment, the overall net biogas production will increase by 4%. This surplus of energy produced represents a potential yearly cost saving of **5694€**. The project to install the high thermal hydrolysis will require an investment of €2.3 Mio. Assuming a discount cash flow of 5%, the net cash flow after 20 years is €-2.12Mio.

This shows that after 20 years, the project investment cost will still be much higher than the income that the surplus of biogas generated thanks to the high thermal hydrolysis pre-treatment will bring. **It is therefore not recommended to invest on such project for energy efficiency purposes at Echternach WWTP.**

4.3.2.3 Summary of energy optimization for Echternach WWTP

For the Echternach WWTP, an analysis for the energy optimization has been performed taking into consideration not only the potential benefit in terms of additional biogas production, but also the economic viability in terms of project return on investment.

In the case of co-digestion, it appears that there will be no significant investment required as the co-substrates considered already exist and would be available in Luxembourg.

For the pre-treatment methods analyzed, they all required investment (initial investment and/or yearly maintenance costs).

The co-digestion methods analyzed will allow significantly increasing the biogas production and the energy self-coverage of Echternach plant from 48.40% to 59% (for OFMSW and GS) and to 64.85% for SM. The co-digestion methods analyze will increase the energy self-coverage of Echternach plant. In the three cases, it will be within the benchmark range.

For the pre-treatment methods analyzed, Lysis centrifuges and high thermal hydrolysis are not appropriated for energy efficiency purposes considering the investment cost required. Only the ultrasonic homogenizer is good not only for energy efficiency purposes, as it would allow increasing the energy self-coverage from 48.40% to 56.33%, but also in term of projects costs as it would allow covering the project cost (yearly maintenance cost) from the first year. The ultrasonic homogenizer pre-treatment method will bring the energy self-coverage of Echternach plant within the benchmark range.

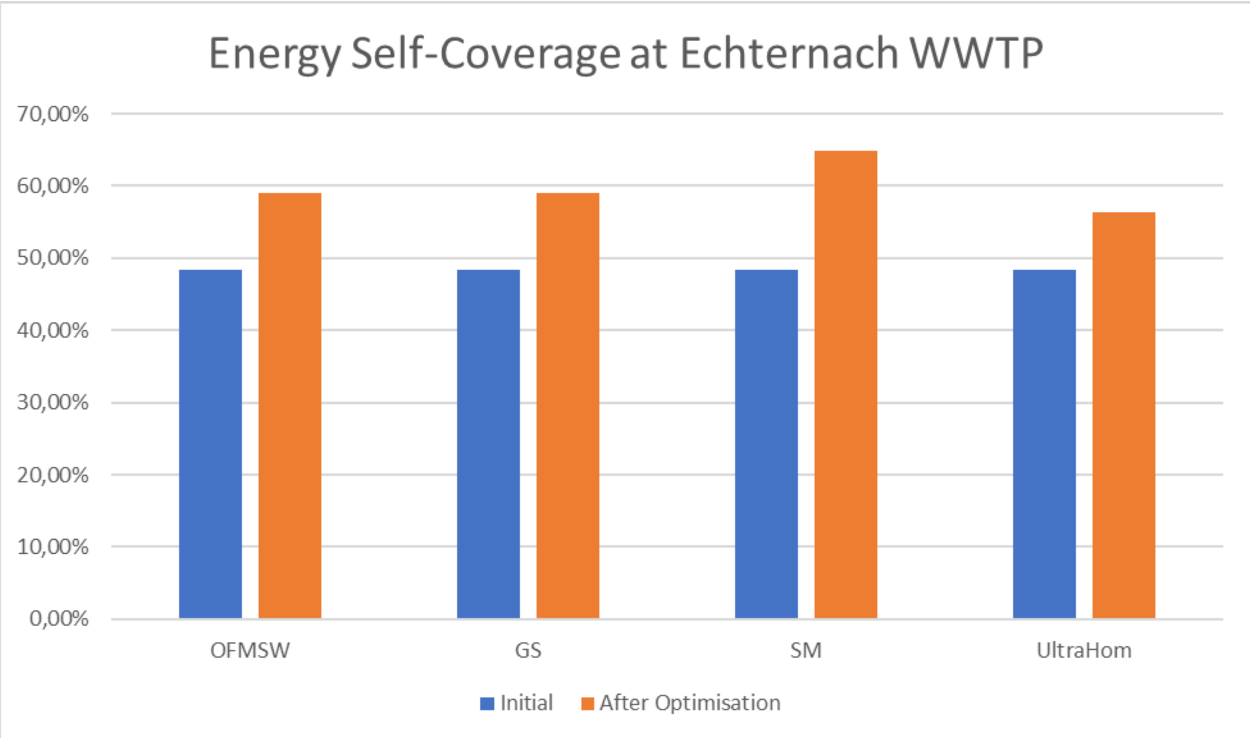


Figure 7: Energy self-coverage after optimization for Echternach WWTP

The Figure 7 above summarized the improvement in term of energy self-coverage of Echternach WWTP. UltraHom in that figure stands for Ultrasonic Homogenizer.

5 Conclusion

An overview of three WWTP of Luxembourg has been done in order to evaluate their energy efficiency in term of energy self-coverage. The three WWTP of Bleesbruck, Mersch and Echternach are similar even if they have been built for a different number of PE. Mersch and Echternach are already using co-generation for the energy recovery, which allows generating heating and electricity from the Biogas produced. They are some important changes planned in the Bleesbruck plant that should be done in 2021. These changes will increase the biogas production from 1300m^3 to 3000m^3 per day and the co-generation will be installed for the energy recovery.

It has been shown here that optimization is possible in term of biogas production by using either co-digestion or some appropriated pre-treatments. Co-digestion with GS, OFMSW and SM could potentially increase the biogas production and the self-energy efficiency of these three WWTP. Moreover, it appears that co-digestion will not require significant cost either in terms of initial investment or in term of maintenance cost. SM appears to be the best co-substrate that will allow having the best energy self-coverage within the three WWTP. Adding co-digestion with SM in the Bleesbruck plant with a mixing ratio of 2.5%-97.5% would make the plant becoming almost energy neutral as the energy self-coverage will get close to the upper value of the benchmark range.

The pre-treatment methods analyzed, excepted for the ultrasonic homogenizer, are not appropriated for the energy self-coverage optimization. It is not recommended to perform Lysis centrifuges or high thermal hydrolysis for the energy efficiency optimization. Indeed, it has been shown that, it will not be possible to recover on economical point of view investing on these two pre-treatment methods. The ultrasonics homogenizer allows improving the energy efficiency as well as the self-coverage of the three stations. Moreover, in term of project, it has been shown that the investment project on ultrasonics homogenizer will allow generating through the additional biogas produced, saving costs much higher than the yearly maintenance cost.

It is recommended adding co-digestion in order to improve the energy efficiency and the energy self-coverage of these three stations. This will be done without requiring additional significant cost as the co-substrate are already available in Luxembourg. SIDEN, SIDERO and SIDEST will gain doing practical case study and implementing these co-digestion methods to increase their energy self-coverage.

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7 Annexes

Pictures showed below are taken from the Bleesbruck booklet available here (SIDEN, 2012).

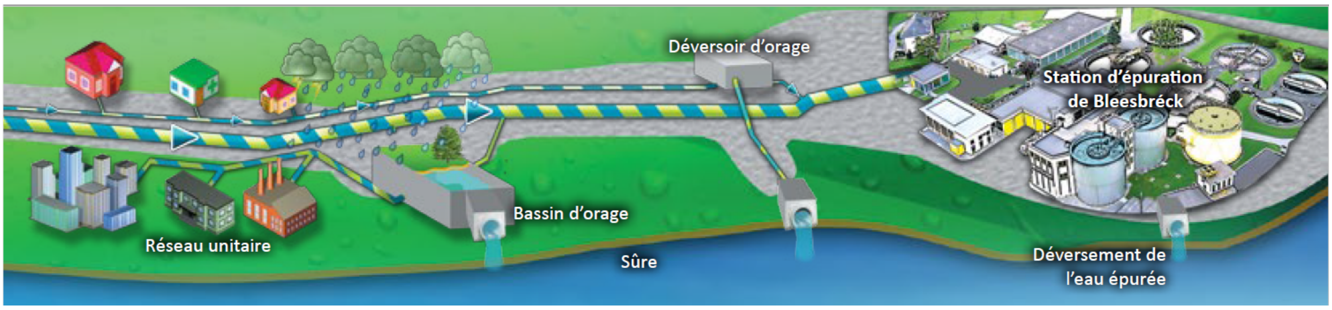

Figure 8: High level View of the Bleesbruck WWTP

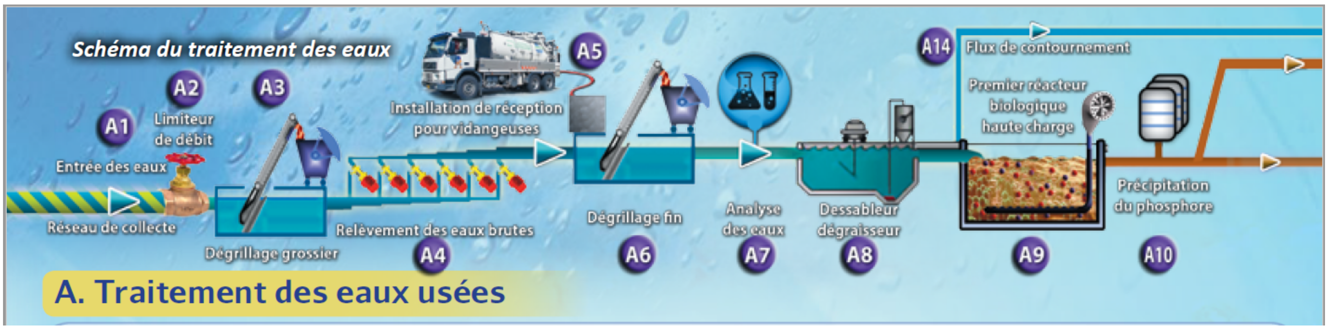

Figure 9: Block Diagram of the wastewater treatment first stage at the Bleesbruck WWTP

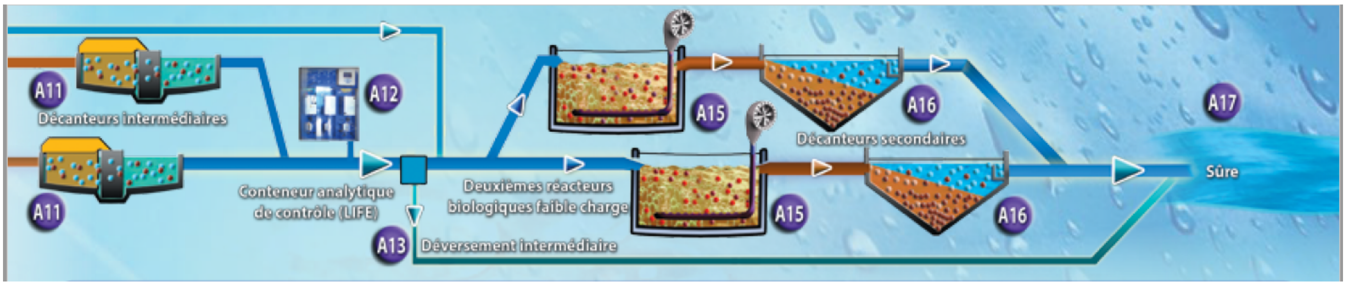

Figure 10: Block Diagram of the wastewater treatment second stage at the Bleesbruck WWTP

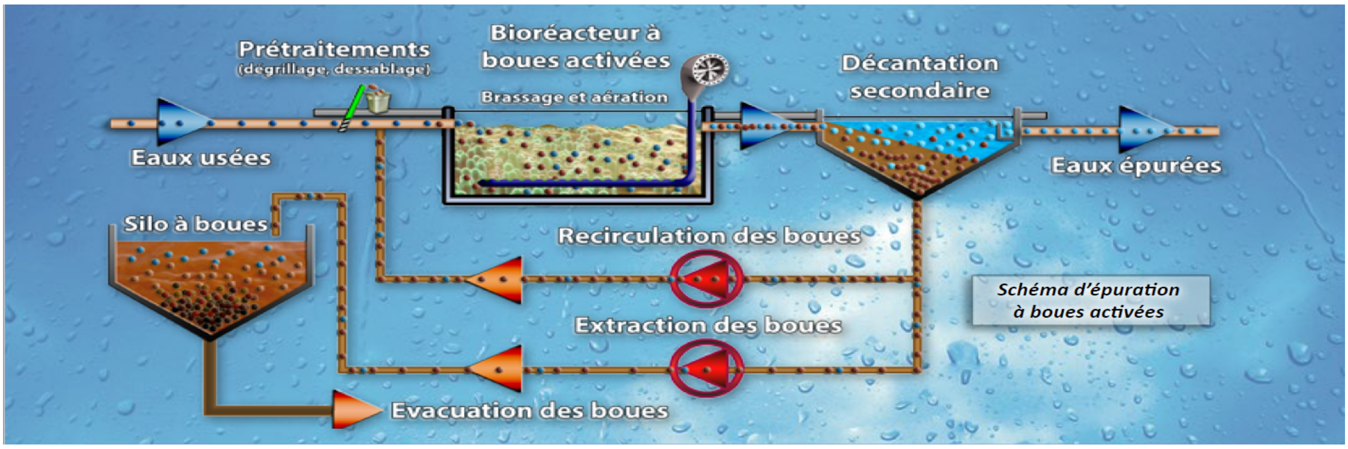

Figure 11: Activated sludge flowdown during the water treatment at Bleesbruck WWTP

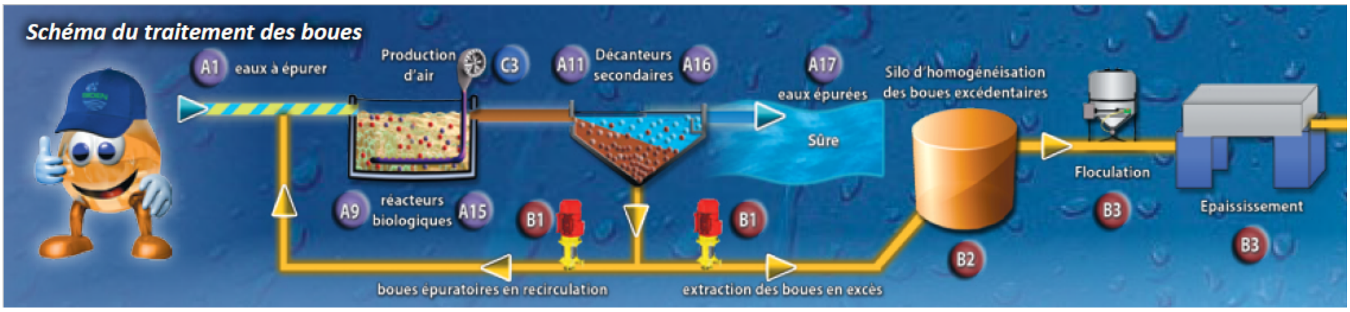

Figure 12: Sludge treatment first stage block diagram at Bleesbruck WWTP

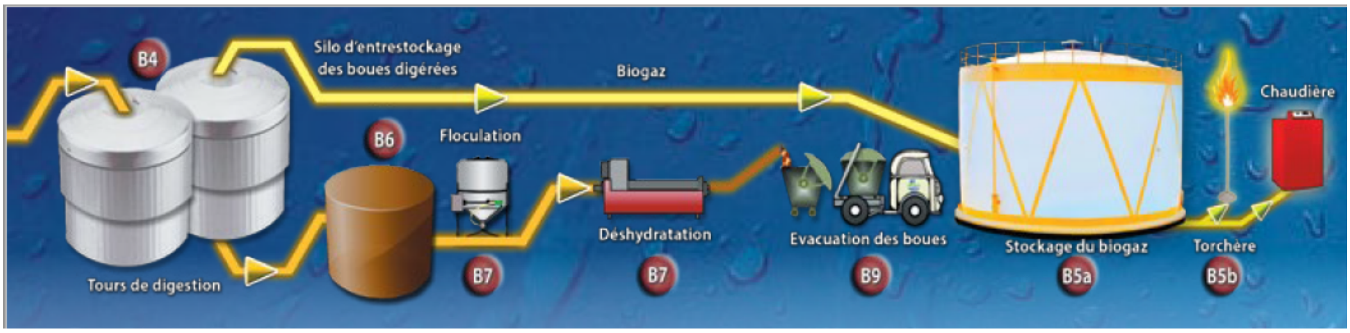

Figure 13: Sludge treatment second stage block diagram at Bleesbruck WWTP

Figure 14: Detailed Illustration of the Bleesbruck WWTP

conversion	1 kWh	1 GJ	1 therm	1 MBtu	1 m3 de gaz	1 bep	1 tep	1 tec
1 kilowatt heure **kWh**	1	0.0036	0.0342	0.0034	0.0949	0.00059	0.00008	0.000125
1 gigajoule **GJ**	277.5	1	9.5	0.95	26.3	0.1634	0.022	0.03467
1 therm	29.27	0.10545	1	0.1	2.78	0.0172	0.0023	0.00365
1 million de Btu **MBtu**	292.7	1.054	10	1	27.8	0.172	0.0232	0.0365
1 mètre cube de gaz **m3**	10.54	0.038	0.36	0.036	1	0.0064	0.00087	0.00136
1 baril équivalent pétrole **bep**	1700	6.12	58.14	5.814	155.5	1	0.135	0.637
1 tonne équivalent pétrole **tep**	12602	45.37	431	43.1	1153	7.4	1	1.573
1 tonne équivalent charbon **tec**	8012	28.84	274	27.4	733	1.57	0.6357	1

Figure 15: Summary of Energy conversion extracted from (Biogaz Methanisation, 2020)

4. CARACTERISTIQUES TECHNIQUES PRINCIPALES

A. Réseau de collecte

Nombre de communes raccordées	10
Nombre de localités/sites raccordés	30
Longueur totale des collecteurs en kilomètres	80
Nombre total de déversoirs	50
Nombre total de bassins d'orage	27
Nombre total de stations élévatoires	24

Charges polluantes des Communes raccordées	
Bettendorf	3.400 EH
Bissen	4.000 EH
Colmar-Berg	5.900 EH
Diekirch	24.700 EH
Erpeldange	5.500 EH
Ettelbruck	15.500 EH
Nommern	2.150 EH
Schieren	2.350 EH
Tandel	1.500 EH
Total ca	**65.000 EH**

B. Station d'épuration

Année de mise en service	1963
Capacité épuratoire nominale initiale	62.100 EH
Capacité épuratoire nominale actuelle	100.000 EH
Débit maximal d'eau traitable par temps pluvial	465 l/s = 1.670 m^3/h = 40.000 m^3/j
Débit moyen d'eau constaté par temps sec	180 l/s = 650 m^3/h = 12.000 m^3/j
Pollution d'entrée DCO / DBO_5 / MES / N_{tot} / P_{tot}	584 / 306 / 272 / 25 / 3,3 mg/l
Charge polluante moyenne constatée été / hiver	90.000 EH / 70.000 EH
Charge polluante constatée en pointe	130.000 EH
Charges urbaines / industrielles / vidangeuses	45.000 EH / 20.000 EH / 25.000 EH
Durée moyenne du traitement de l'eau	7,5 heures (temps sec)
Durée moyenne du traitement des boues	3 semaines
Effluent épuré moyen DCO / DBO_5 / MES / N_{tot} / P_{tot}	56 / 16 / 18 / 23 / 1,8 mg/l
Rendement épuratoire moyen DCO / DBO_5 / MES / N_{tot} / P_{tot}	90 / 95 / 93 / 8 / 44 %
Production annuelle de refus de dégrillage	120 tonnes
Production annuelle de sables	100 tonnes
Production annuelle de huiles et graisses	40 tonnes
Production annuelle de boues à 30% MS	2.200 tonnes
Production annuelle de biogaz	500.000 m^3
Consommation annuelle d'eaux industrielles (puits)	90.000 m^3
Consommation annuelle en énergie électrique	3 GWh
Personnel de maintenance	7 agents

Coût effectif du traitement de l'eau mixte	0,70 €uro/m^3
Coût théorique du traitement de l'eau usée	2,00 €uro/m^3

Figure 16: Bleesbruck WWTP Datasheet

Here below is a picture of Mersch WWTP:

Figure 17: Mersch WWTP overview

Echternach WWTP overview is given below:

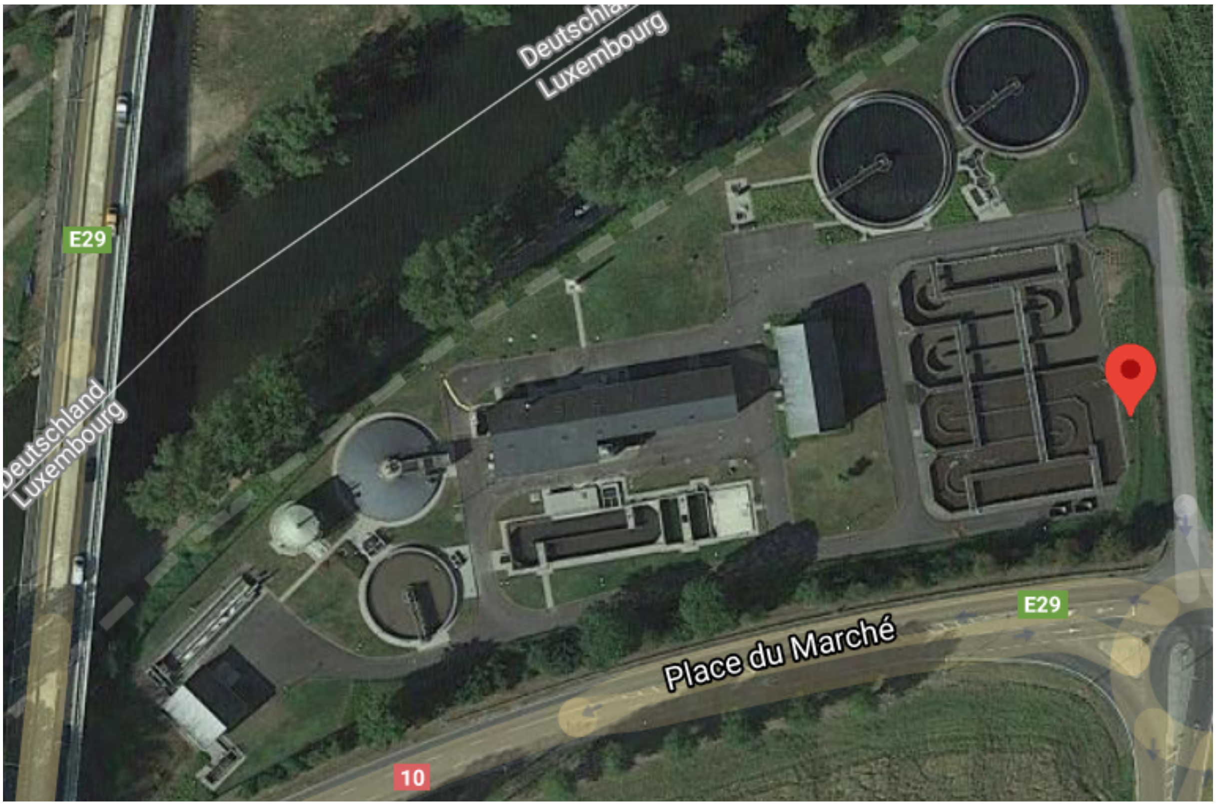

Figure 18: Echternach WWTP overview