No. B 2346
May 2019

LCC - Biogas at a food production plant

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In cooperation with Food producing company

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Funded by: Stiftelsen IVL
Photographer: Click and add text
Report number B 2346
ISBN 978-91-7883-046-6
Edition Only available as PDF for individual printing

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Preface

This report presents work performed during the spring of 2019. The study is carried out in cooperation between IVL Swedish Environmental Research Institute and ADahl Konsult. The project was jointly financed by the IVL foundation and the Food producing company.

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Summary

The aim of this study was to investigate different options for utilization of residual products from food-production and has been performed together with a specific company active in that branch. The food producing company (FPC) is drastically increasing the production at their plant which results in more residual products from their processes. This, in-turn, has the effect that they need to establish new on-site facilities for handling of these increased residual streams.

Hence, this study investigates the possibilities and consequences of investing either an on-site sewage treatment facility (alternative A) or the former combined with an on-site biogas production facility (alternative B) for a food producing company. The methodology used for evaluating these two options for the company is Life cycle cost (LCC) analysis.

Extensive efforts have been made during this study to include as relevant and high-quality in-data as possible. This data has been retrieved from studies previously performed by various firms for the company and from thorough discussions between IVL and the company.

The analysis of LCC-results can be used to determine which option is the most financially preferred from the company's standpoint, in terms of LCC, Straight payback time (PT), and Net present value of investment (NPVoI). In this study, with the base parameters used, the LCC for alternatives A and B are 31.1 MSEK, and 6.56 MSEK, respectively. The PT is 5.8 years, meaning that B has a higher probability for making a profit for the company, in comparison to alternative A. The NPVoI for B is 24.6 MSEK, making it a profitable option of investment for the company.

To determine how various parameters and factors influence the results, an extensive sensitivity analysis was also included in this study where several parameters were altered. The NPVoI is influenced by all parameters in the following order of influence: i) biomethane price of the grid, ii) revenue from fiber sludge, iii) calculation period, iv) interest rate, v) investment cost sewage treatment plant, vi) revenues biofertilizer, vii) investment cost biogas plant, viii) electricity price, and ix) sludge revenue/cost. This is a measure of how important the individual parameters are for the company's decision on how to proceed with their investment plans.

The two most important parameters hence are: Biomethane price of the grid and revenue from fiber sludge. Thus, the higher the market price of biomethane, the more sense in makes to have an in-house biomethane production plant. The company is considering achieving a more "vegetarian/vegan"-profile in which case the fiber sludge cannot be sold as animal feed. If the sludge cannot be sold for this purpose, the revenue from it goes down and the more sense it makes to have an in-house biogas production facility.

Sammanfattning

Målsättningen med denna studie var att undersöka olika möjligheter för användning av residualprodukter från livsmedelsproduktion och har utförts ihop med ett specifikt bolag i den branschen. Livsmedelsföretaget ökar dramatiskt sin produktion vid sin fabrik vilket resulterar i mer residualprodukter från processerna. Detta får vidare effekten att de behöver etablera nya anläggningar på sin site för att ta hand om dessa ökade residualflöden.

Denna studie undersöker således möjligheterna och konsekvenserna för ett livsmedelsproducerande företag att investera i en anläggning för avloppsrening (alternativ A) eller detta i kombination med en biogasproduktionsanläggning på plats (alternativ B). Metoden som används för att utvärdera dessa två alternativ för företaget är livscykelkostnadsanalys.

Omfattande insatser har gjorts för att erhålla så relevant och högkvalitativ in-data som möjligt. Dessa uppgifter har hämtats från studier som tidigare utförts av olika firmor på uppdrag av det livsmedelsproducerande företaget och från grundliga diskussioner mellan IVL och företaget.

Analysen av LCC-resultat kan användas för att bestämma vilket alternativ som är mest ekonomiskt att föredra ur företagets synvinkel, vad gäller livscykelkostnad (LCC), Rak återbetalningstid (PT) och Netto nuvärde av investeringar (NPVoI). I denna studie är LCC för alternativ A och B med basparametrar 31,1 MSEK respektive 6,56 MSEK. PT är 5,8 år, vilket innebär att B kommer att leda till bättre vinstmöjligheter för företaget, i jämförelse med alternativ A. NPVoI för B är 24,6 MSEK, vilket gör det till ett lönsamt investeringsalternativ för bolaget.

För att avgöra i vilken utsträckning olika parametrar och faktorer påverkar resultaten, så ingick även en omfattande känslighetsanalys i denna studie där flera parametrar ändrades. Netto nuvärdet av investeringen påverkas av alla parametrar i följande inflytandeordning: i) Biometanpris från nätet, ii) Intäkter från fiberslam, iii) Beräkningsperiod, iv) Kalkylränta, v) Investeringskostnad reningsverk (vi) Intäkter Biogödsel, vii) Biogasanläggningskostnad, viii) Elpris och ix) Slamintäkter / -kostnader. Detta är ett mått på hur viktigt de enskilda parametrarna är för företagets beslut om hur man går vidare med sina investeringsplaner.

De två viktigaste parametrarna är: biometanpriset från nätet och intäkterna från fiberslam. Ju högre priset på att köpa biometan på marknaden, desto vettigare är det att ha en egen biogasproduktionsanläggning. Om företaget väljer att försöka uppnå en mer "vegetabilisk" -profil, så bortgår möjligheten att sälja fiberslammet för djurfoder. Om slammet inte kan säljas för detta ändamål, så minskar intäkterna från det och gör det därmed mer förnuftigt med en egen biogasproduktionsanläggning.

Acronyms

FPC	Food Producing Company
LCC	Life cycle cost
PT	Straight payback time
NPVoI	Net present value of investment
WWTP	Waste Water Treatment Plant
BPP	Biogas Production Plant
MBBR	Moving Bed Biofilm Reactor
OPEX	Operating Expense
CAPEX	Capital Expense
NPV	Net Present Value
Q	Flow
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
NO23-N$_{max}$	Nitrate + Nitrite Nitrogen
SÄ	Suspended Substances
UASB	Upflow Anaerobic Sludge Blanket
EGSB	Expanded Granular Sludge Bed
IC	Internal Circuit
HRT	Hydraulic Retention Time
VS	Volatile Solids
DM	Dry Matter
CSTR	Continuously Stirred Tank Reactor
BMP	Biochemical Methane Potential

1 Introduction

Pre-industrial food consumption consisted primarily of vegetable material. However, as the standard of living increased throughout the world, the ratio of animal feed-stock for food production has gradually increased [1,2]. In recent years, a growing part of the population in Sweden, and many similar countries, have started to request more food-products from purely vegetable feedstocks [3]. Various food producers have tried to meet this growing demand with increased industrial production of suitable food products. The company focused on in this study, is one of these companies.

Furthermore, there is also a strong drive in society to reduce the utilization of fossil resources to reduce the human impact on climate and to establish more sustainable production processes in industry [4,5]. This drive is particularly strong in the Nordic countries and the main consumer-group for products from the food producing company reviewed in this study are supportive [3].

With the increased demand, current producers have continued expanding production across Sweden. This drastic expansion of production volumes at food producing companies can affect the ability for regional wastewater and residual material handling at the municipal sewage treatment facilities; which may be unable to cope with the increased volumes. In order to allow for such expansion, the food producing company, require environmental permits for internal sewage water treatment and handling of their residual products. The food producing companies wish to gain knowledge about which is the most energy- and cost-efficient solution for handling of sewage sludge from aerobic treatment and residual product. This partly includes valorization of the residual streams by internal utilization.

Due to the increase in production volume, FPC needs to find a way of dealing with residual handling internally. The minimum action they need to take is to construct a Waste Water Treatment Plant (WWTP) at their facility. Another possible option is to include a Biogas Production Plant (BPP) in their solution to the problem. For the latter case, the produced biogas could be used internally for production of industrial process-steam and the biofertilizer used to replace mineral fertilizer in agriculture. The food producing company wants to gain insight in which of these two options is the most favorable investment for them.

The company WSP has previously made dimensioning calculations of the treatment process for different prerequisites employing different techniques. Following this, Veolia has proposed aerobic sewage water treatment in a system based on other prerequisites (loads) than in the previous WSP studies. On the basis of changed prerequisites, the dimensioning made by WSP is considered obsolete and a new dimensioning is therefore performed in this study.

The company focused on in this study is producing food products. Fibre sludge is formed as a residue from the process and this sludge can be utilised as a raw material for biogas production. A wastewater plant will also be installed, and this plant will produce a primary sludge from flotation as well as aerobic sludge from a MBBR unit. Sludge from the wastewater treatment plant can be mixed with the fibre sludge as raw material for biogas production. Heat is used in the production process and the boiler is fired with natural gas today. Biogas from internal residues could replace some of the natural gas as fuel to the boiler.

When purchasing energy-intensive products or making investment decisions between different options, it is important not only to look at which alternative is the cheapest at the time of purchase, but also which option has the lowest operating costs and is the cheapest to maintain. Operational and maintenance costs during the lifetime of the product can be a larger part of the total costs of the investment; this can be done using life cycle costing (LCC). Using the LCC-methodology, one can compare the costs of competing systems or equipment throughout their lifetime [6,7].

This study employs LCC analysis to compare the two possible solutions the food producing company has. Alternative A: on-site WWTP, and alternative B: on-site WWTP combined with on-site BPP. In addition to this an extensive sensitivity analysis is carried out to map the influence different parameters have on the LCC results. The report should be read as a stand-alone document with emphasis on the LCC analysis and the implications the results may have for similar stakeholders looking into utilizing residual products.

1.1 Purpose and goal

This project has the following goals:

- Conduct Pre-planning to determine OPEX and CAPEX for a biogas plant located at the factory site of the food producing company.
- Perform a Life cycle cost analysis which compares a base-case with a scenario including on-site biogas production
- An English report (this document) which can be used as a basis for strategic decisions for food producing companies

The results of the project will contribute to knowledge development for organizations considering using their residual products internally to produce energy instead of external disposal.

1.2 Scenarios

The following two scenarios are compared in this study. The option of not taking any action to meet the problems described above does not exist for the food producing company. The minimum action is described in alternative A, and the more ambitious action is described in alternative B. The current situation is depicted in Figure 1, and alternative A and B is shown in Figure 2 and 3, respectively.

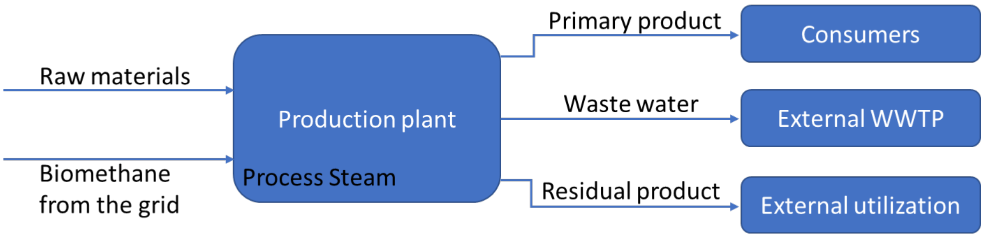

Figure 1. Schematic overview of the current situation at the FPC.

1.2.1 Alternative A: Base-case

- Purchasing of biomethane (natural gas quality) through trader used for steam production
- On-site industrial sewage water treatment
- Sewage sludge is transported for external biogas production
- Residual product (fiber sludge) is transported to farms and used as animal feed

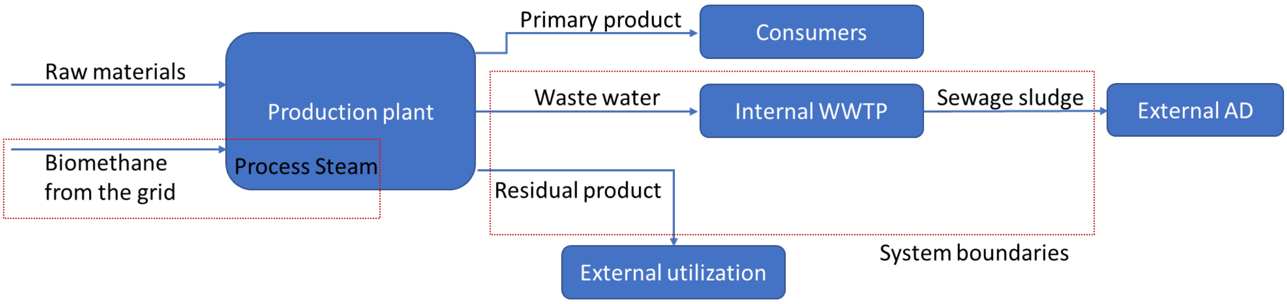

Figure 2. Schematic overview of alternative A for handling of residual streams. This represents the minimum required action. The system boundaries for this study is shown in red.

1.2.2 Alternative B: Biogas scenario

- On-site industrial sewage water treatment
- On-site biogas production from sewage sludge and residual product (fiber sludge)
- Biogas used for process steam production
- Biofertilizer transported to farmlands

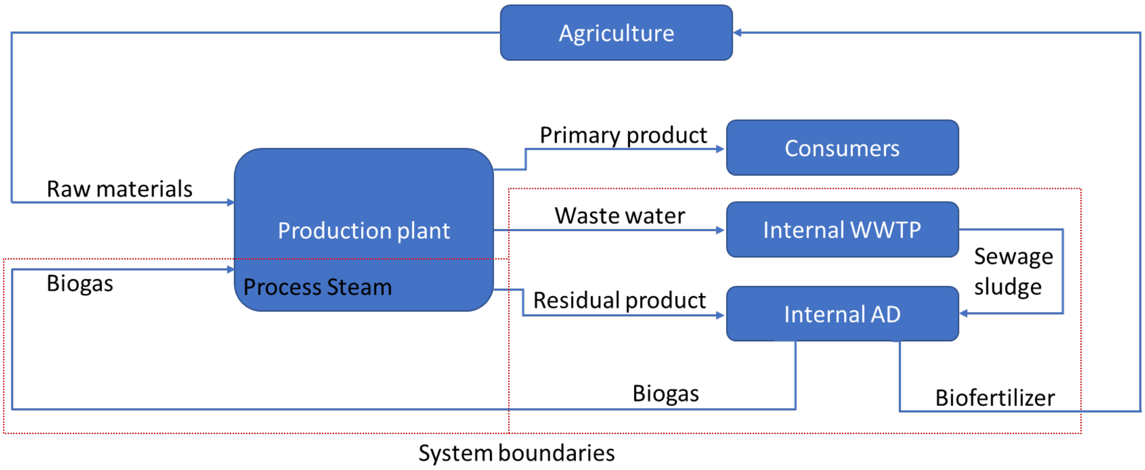

Figure 3. Schematic overview of alternative B for handling of residual streams. This represents a more ambitious action. The system boundaries are shown in red. Note the increased circularity of this approach.

2 Methods

2.1 Waste Water Treatment Plant (WWTP)

The dimensioning of the WWTP was performed by Andriy Malovanyy, IVL, and colleagues employing their in-house methodology and expertise. The methods used are not publicly available.

2.2 Biogas Production Plant (BPP)

The dimensioning of the BPP was performed by ADahl konsult employing their in-house methodology and expertise. The methods used are not publicly available.

2.3 Life Cycle Cost (LCC)

A LCC assessment is usually based on the so-called present value method. The present value method is used to recalculate expected future expenses and any revenue to a value today, the so-called net present value (NPV). When calculating, a discount rate, because a krona today does not have the same value as a krona tomorrow. All future costs are recalculated to the time of purchase. In this way, future costs can be compared to current costs. This makes it possible to compare products and services in an equivalent way over time, since they compare the total cost over the useful life. Calculation of life cycle costs is used to choose between different investment options. Usually, it is used when one has already decided to implement a certain investment, but there are several different measures to choose from. Calculation of life cycle costs can also be used to assess an investment's profitability, to determine whether to carry out the investment or not. Then the investment alternative is compared to the alternative of not doing anything at all. For profitability assessments, there are also more methods where straight payback time is the simplest - and perhaps most common. The LCC tool can also be used for calculating the payback time [6]. The general equation for NPV is depicted below.

Eq. 1

$$NPV = -IN + \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t}$$

, where *NPV* is the Net Present Value, *IN* is the Initial cost of acquisition, *CF* is the cash flow, r is the discount rate, t is the Analyzed period (time), and T is the Life Cycle (Tenure) [8].

This study uses the deterministic approach and employs expert assessment of input values. Thus, Life Cycle Cost could be calculated by the following formula:

Eq. 2

$$LCC = C_A + \sum_{t=0}^{LC} \frac{C_t}{(1+r)^t}$$

, where *LCC* is the current value of Total Life Cycle Cost, C_A is the Acquisition cost, r is the Discount Rate (time value of money), *LC* is the Life Cycle, and C_t is the sum of relevant Life Cycle Cost of property after deducting the positive cash flow [8].

2.3.1 Calculation period

The lifetime of an investment is not necessarily the same as the technical life, that is, how long the equipment is expected to last. In investment calculations, one should use an economic lifetime, which is normally shorter than the technical one, which is because maintenance costs increase with age and that the development of alternative solutions progresses. One alternative is to use an estimated useful life or usage time. Different equipment can have different economic life or service life. When different options are compared, therefore, a common calculation period must be selected so that all alternatives are compared over an equal time period. If the chosen calculation period is shorter than the economic life or the useful life of any alternative, the residual value for that alternative must be estimated at the end of the calculation period. If one instead chooses a calculation period that is longer than the shortest operating time for any alternative, one must assume that it is possible to reinvest in that option when its useful life is over. In this study, the calculation period was set to 30 years for construction and land and to 15 years for the respective facility, including process, electric installations and tubing etc.

2.3.2 Interest rate

The calculation interest rate is used to recalculate payments made in the future to the current monetary value. The higher the cost of capital, the higher the weight that is close to the time and the lower the costs that lie further into the future are weighted. The cost of capital to be used is generally determined by the loan rate, the lowest acceptable return for the investor, and the risk associated with the investment. Like the choice of calculation period, the choice of interest rate should be common to all options. It can be difficult to choose the interest rate and the company’s investment guidelines should be used if available. It can also be good to make a sensitivity analysis by varying the value of the interest rate in the LCC calculation to see how profitability and life cycle cost are affected. In this study the interest rate was set to 4% for the base-case and varied in the sensitivity analysis, see below.

2.3.3 Types of energy

Here, the energy type or types are stated, the use of which is affected by the investment. Energy types can be, for example, electricity, district heating, fuel for steam production, or some other type of energy. This study used the energy types electricity, heat, biomethane (grid quality), and raw biogas.

2.3.4 Energy price for different types of energy

The current price that the company pays for each type of energy. This study used the prices in table 1 for different types of energy.

Table 1. Energy prices used in the study, retrieved in discussions with the food producing company.

Type of energy	Price (SEK/KWh)
Electricity	1
Heat	0.6
Biomethane	0.75
Raw Biogas	N/A

The different types of energy are all subjected to the sensitivity analysis below.

2.3.5 Investment costs

Investment costs include initial one-time cost in connection with purchasing and installation. The total investment cost for the sewage treatment plant alone was calculated to be roughly 44 MSEK, and the total investment cost for the biogas plant alone was calculated to 30.4 MSEK. The two interconnected plants influence the operation of each other however and therefore, synergies arise. This makes the total investment cost for constructing both plants lower than the sum of the individual costs, 68.4 MSEK.

2.3.6 Annual energy requirement for different types of energy

The annual energy requirement is estimated based on the power and operating time of the equipment (energy requirement = power x operating time). For the calculation of profitability (repayment time and net present value), only energy requirements that differ between the alternatives need to be specified. The sewage treatment plant and the biogas plant were calculated to require around 527 MWh/y and 800 MWh/y of electricity, respectively. In addition to this, the latter require approximately 800 MWh/y of heat.

2.3.7 Operating and maintenance costs

Costs for maintenance are normally stated as a fixed annual cost. In special cases, costs for individual years can be specified. (The costs must be stated without inflation, that is, in today's monetary value, because it is the real cost of capital used in the present value calculations). In this study the operating and maintenance cost for the sewage treatment plant included: electricity consumption (527 kSEK/y), acid consumption for adjustment of pH (139 kSEK/y), flocculant consumption (145 kSEK/y), polymer consumption (323 kSEK/y), sludge disposal (0 kSEK/y), personnel costs (416 kSEK/y), and maintenance (365 kSEK/y). Likewise, for the biogas plant included: electricity consumption (800 kSEK/y), heat consumption (480 kSEK/y), consumption of chemical additives (250 kSEK/y), cost for analysis (75 kSEK/y), personnel costs (416 kSEK/y), and maintenance (274 kSEK/y). In addition to the above costs, revenue from fiber sludge was calculated to 2.4 MSEK/y, revenues from biofertilizer calculated to 288 kSEK/y, and savings from remediated purchases of biomethane from the grid to around 8.4 MSEK/y. These costs and revenues are valid for the base case in the sensitivity analysis below and thus individually affected by changes made to in-data values.

2.3.8 Other costs

In other costs, any added value of an investment option can also be stated if it is possible to set a price on the value. As the study compares at least two different options, it may be easier to specify the difference between the alternatives instead of the absolute costs. Other costs may include, for example, any environmental costs. No such costs were included in this study.

2.3.9 Residual value

The residual value includes any remaining financial value after the calculation period. The residual value for the sewage treatment plant and the biogas plant was calculated to amount to 7.5 MSEK and 9.5 MSEK, respectively.

2.4 Sensitivity analysis

The sensitivity analysis was made on parameters changed in accordance with input from the food producing company and internal experts in respective field. Based on previous experiences of the FPC and IVL, the individual parameters were varied over a range deemed plausible in the context of this study.

3 Results

3.1 Waste Water Treatment Plant (WWTP)

This chapter discusses the prerequisites, describes the dimensioning of the new treatment process and discusses assumptions used in the dimensioning calculation.

3.1.1 Loads

Based on the calculations made by WSP and Veolia, Q_{mean} after the buffer tank has been set to 40 m^3/h and $Q_{max}=Q_{dim}=80$ m^3/h. The sewage water treatment facility is dimensioned for a maximum daily load of BOD= 4000 kg/d and COD=6400 kg/d. It has also been assumed that all COD is biodegradable.

Since there are uncertainties about how much of the nitrogen that originates from washing equipment, and how much that comes from the neutralization, and if it is possible to replace the washing chemical with an alternative that does not contain nitrate, the following loads are assumed according to the precautionary principle:

- Total nitrogen load 150 kg/d, which is slightly lower than maximum daily load
- Nitrate/nitrite nitrogen constitutes 50% of nitrogen load, i.e. 75 kg/d.

The design of total nitrogen load has been chosen lower than the maximum daily load according to Veolia's compilation (150 kg/d instead of 185 kg/d) as the load is likely to be reduced by the use of an alternative neutralization agent and since - in the case of medium-load days - emission levels of nitrogen will be very low, which creates the possibility of slightly higher emissions of nitrogen at maximum load. Furthermore, it has been assumed that in all studied alternatives there is no internal load with nitrogen, for example from dewatering of biofertilizer. If digestate is dewatered prior to removal, nitrogen in the reject water will increase the total nitrogen load by approximately 30 kg/d.

According to the food producing company the dimensioning should be based on the temperature 30 °C. It has further been assumed that no cooling is needed to reach that temperature. If the temperature in the biological step exceeds 35 ° C, it will lead to a large loss in viability (and overall death) of microorganisms and total loss of purification capacity for about 1 week. The temperature in the biological step can also rise by a few degrees due to high biological activity (exothermic process) and heating with warm air from the aeration. It should therefore be considered in final design if the possibility of cooling is needed. Biological activity is temperature dependent and decreases by 5-10% for each ° C decrease in temperature. If there is a risk that the temperature can be lower than 30° C as a daily mean, especially in combination with high load, the dimensioning should be changed to a lower temperature.

3.1.2 Compilation of design data

The conditions for dimensioning the biological treatment step and description of what the parameter has been used for are summarized in Table 2.

Table 2. Summary of biological treatment design data.

	Value	Used for dimensioning of:
Flow, Q_{max} after buffer tank, m^3/h	80	Flocking, floatation, drum filter
Q_{mean}, m^3/d	832	Flocking
Q_{max}, m^3/d	1 100	Buffer tank
BOD_{mean}, kg/d	2 020	MBBR
COD_{mean}, kg/d	3 500	MBBR, potential for biogas production
BOD_{max}, kg/d	4 000	MBBR
Tot-N_{mean}, kg/d	100	N in sludge to digester
Tot-N_{max} bio, kg/d	150	MBBR
TKN_{mean}, kg/d	52	Need for external N-dosage, N in sludge to digester
NO23-N_{max}, kg/d	75	MBBR
$SÄ_{mean}$, kg/d	970	Amount of sludge
Tot-P_{mean}, kg/d	10	Precipitation

The treatment plant was designed to meet the following purification requirements:

- 8 mg/l BOD7/l calculated as quarterly average
- 0.3 mg Tot-P calculated as half-year average
- 10 mg Tot-N calculated as annual mean

3.1.3 Aerobic treatment in MBBR

According to both investigated scenarios, it has been decided that biological aerobic treatment is required in the MBBR (Moving bed biofilm reactor) process. The selected process design is similar to the design proposed to the FPC in a previous study [9] and is illustrated in Figure 4.

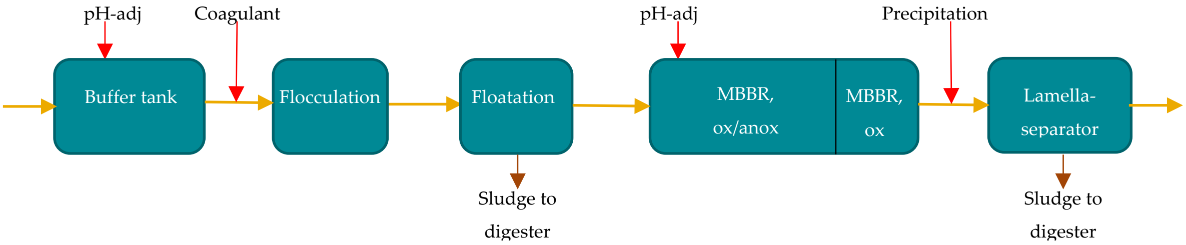

Figure 4. Design of the MBBR-process.

All steps of the process are described in the following sections.

3.1.3.1 Buffer tank

There is no good basis that shows the expected variation of the incoming flow from the factory in absolute values (m^3/h). It has therefore been assumed that for equalization of flow variations, a volume corresponding to the residence time of 3 h is required at the maximum daily flow (about 140 m^3). It has also been assumed that the composition of the water varies a little during the day (no large shock-resistant BOD7 or Tot-N emissions from the factory during a certain time of day). Then the residence time corresponding to 4 hours at maximum daily flow should be sufficient for equalization of organic and nitrogen load. Total volume of the buffer tank has been chosen to be 320 m^3.

3.1.3.2 Flocculation and floatation

Incoming water contains relatively high levels of fat, and flotation has therefore been chosen instead of sedimentation as the primary mechanical purification step. To improve the separation of suspended particles, coagulant (organic polymer or iron or aluminum-based coagulant) is dosed and particles are flocculated in a flocculation chamber sized for 10 minutes residence time at maximum flow. It has been assumed that the coagulant is the same as that used for the precipitation of phosphorus before the drum filter (the same chemical tank).

Reduction of suspended material has been assumed to be 75% (71% in WSP's precipitation propagation with slightly lower incoming suspension content). At the assumed reduction rate, approximately 40% of incoming COD will be separated by sludge which is led to digestion.

3.1.3.3 MBBR

According to WSP's proposal, the MBBR was divided into two zones (350 m^3 + 220 m^3) where in the first zone denitrification occurred under anoxic conditions and in the aerated zone aerobic BOD degradation occurred. The disadvantage of this solution is that if incoming water contains too little nitrogen, in organic and ammonium form, there will be no nitrogen in the aerobic zone for sludge production which can adversely affect the BOD separation.

According to IVL's dimensioning, the biological purification consists of an MBBR distributed between two zones - 500 m^3 and 50 m^3.

The majority of BOD and nitrogen are separated in the first zone which is aerated intermittently. The zone is equipped with both aeration and agitation. During the stirring phase (anoxic conditions, about 20% of the time), denitrification occurs and during aerated phase (aerobic conditions, about 80% of the time) aerobic BOD degradation occurs. The second aerated zone is continuously aerated and acts as a BOD polishing step. Since the majority of BOD is separated in the first zone, the oxygen content in the second zone will be high in normal operation.

Control of phases in zone 1 is achieved by measurement of nitrate content in the first zonewith over-regulation of the oxygen content measured in the other zone. Oxygen content in zone 1 is manually selected or controlled by the oxygen content in zone 2.

At medium load, changeover from aerated to un-aerated phase (and vice versa) will be made to keep the nitrate content at a stable low -level. The oxygen content during the aerated phase can be kept at a low level (about 1.5 mg/l). The oxygen content in the second zone will then be high (> 5 mg/l) because most of the BOD is separated in zone 1. When the BOD load rises, the oxygen content will fall in zone 2 as it will get more BOD. In descending oxygen levels, the setpoint in zone 1 can be increased automatically to increase the BOD separation. If the oxygen content in zone 1 is already high (5 mg/l) but it is not enough to raise the oxygen content in zone 2, the changeover to un-aerated phase will be interrupted and thus the purification of nitrogen will be short-term sacrificed to maintain stable high BOD reduction.

Advantages of the proposed solution with intermittent aeration are that (1) the dosing of external nitrogen is not needed; (2) capacity for BOD reduction and denitrification can be flexibly changed depending on load; (3) energy consumption is lower since oxygen value control is done automatically (lower oxygen content gives more energy efficient oxygen transfer); and (4) most of the load is separated in the first zone, which means that the zone also equalizes partly incoming load and gives lower consumption of the pH adjustment chemical.

3.1.3.4 pH adjustment

There are two alternative points for pH adjustment - in the buffer tank and in the MBBR. There are also various options for choosing the chemical for pH adjustment:

- *Detergent containing nitric acid*. This is possible only if consumption for pH adjustment is very small, otherwise cheaper with other options. Also increases nitrogen load.
- *Sulfuric acid*. The advantage is that it is cheaper than detergent. Can be dosed in both dosage points. Consumption is expected to be much less if it is dosed in the MBBR because the production of CO_2 in the biological process lowers the pH. Good fat separation, however, may require low pH already in the flotation. The disadvantage is that a certain minor part will come in the digester, which results in higher production of hydrogen sulphide.
- *Hydrochloric acid*. The advantage is that it does not affect hydrogen sulphide production but is more expensive than sulfuric acid (though cheaper than detergent).
- *CO_2 from possible upgrading of biogas*. Neutralization with CO_2 is most appropriate to do in the buffer tank by "aeration". The amount of CO_2 available should be sufficient for pH adjustment. Theoretically, the MBBR can also be supplied through the aeration system during the anoxic phase.

There is not enough available information to make a safe calculation of the consumption of the neutralization chemical. Consumption of acid for neutralization has been calculated based on the following assumptions:

- Nitrate nitrogen in wastewater only comes from nitric acid in the washing chemical.

- The washing chemical is mostly used for washing tanks (2/3 parts of consumption) and to a lesser extent (1/3 of consumption) for pH adjustment of incoming sewage.
- Consumption of acid for neutralization of 1 m^3 of water will in the future be the same as today.

These assumptions require dosing of acid of 2.3 eq./m^3, which for 98% sulfuric acid corresponds to 0.11 kg/m^3.

3.1.3.5 Precipitation and sedimentation

In biological purification sludge is formed which must be separated before discharging water to the recipient. In addition, phosphorus must be precipitated. After the MBBR, the Fe or Al-based precipitation chemical is dosed. Then, the water is led to a lamella separator with associated flocculation chamber. In WSP's preliminary study [9], it was proposed that drum filters be used for separation of sludge. However, the calculation of sludge production shows that the suspension content in the water after the bio-purification will be about 800 mg/l. At such a high suspension content, frequent washing of the filter will be required, which will increase internal hydraulic load on the entire system.

3.1.4 Amount of sludge

Sludge production consists of primary sludge which is extracted from the floatation and bio sludge which is extracted from the lamella separator. Both sludge fractions also contain a small amount of chemical sludge formed from dosing the Fe or Al based chemical. Primary sludge has a higher degree of digestion. Therefore, the expected sludge production for the two sludge fractions is presented separately in Table 3.

Table 3. Amounts of sludge produced in sewage treatment plant.

	Primary sludge	Bio sludge
TS, kg/d	780	730
VS, kg/d	710	600
COD, kg/d	1 410	840
Tot-N, kg/d	18	48
Tot-P, kg/d	1,5	8,3
TS	1,5%	1,5%
Flow, m^3/d	50	50

If the sludge will be digested in an on-site biogas plant, it may advantageously be thickened before mixing with other substrates to obtain the correct incoming TS content. As it is sufficient to increase the maximum TS content to 3%, gravity thickening can be used. Suitable dimensions for the gravity thickener are 6 m in diameter and 3 m minimum depth, which gives a basin volume of about 85 m^3. If the sludge will be sent to another biogas plant or deposited as a biofertilizer, it will have to be dewatered to a higher TS level in order to reduce the transport costs. It is then appropriate to supplement the treatment plant with a decanter centrifuge which dehydrates the sludge from 3% TS to about 25% TS. These additional measures are included in the calculations

3.1.5 Option of anaerobic treatment in WWTP

There is potential for increasing biogas production through the use of anaerobic treatment of sewage water. This option is not included in the study and therefore only a summary is presented.

In aerobic purification treatment to the above proposal, about 40% of COD is separated as primary sludge and led to digestion. Around 10% is used as carbon source for denitrification and the remaining COD amount is separated aerobically. In aerobic purification, part of the COD is mineralized to CO_2 (about 60%) and the rest is bound to the bio-sludge (about 40%). However, the biological sludge has a low degree of digestion. In total, only about 37% of the total incoming COD in the wastewater will be recovered as methane in the dimensioned system. If the dissolved fraction of COD is anaerobically separated, recovery of COD in the form of methane can be maximized and biogas production increased by about 80% compared to aerobic purification.

Depending on the choice of anaerobic system, the following conditions may constitute an obstacle to anaerobic purification:

- *Fat.* Fat must be reduced to below 50 mg/l if the water is to be purified in highly loaded anaerobic reactors (e.g., UASB, EGSB, IC);
- *Suspended substances.* Highly loaded anaerobic reactors may be susceptible to suspended material and the recommended maximum suspension is 100-400 mg/l depending on the type of anaerobic reactor. The mean content of SÄ is 1165 mg/l, which means that a reduction of 65-90% is required.
- *Nitrate*. Nitrate must be separated before anaerobic purification as it increases the redox potential and inhibits anaerobic degradation of organic substances.
- *Nitrogen*. Less sludge is produced in anaerobic purification, which means that less nitrogen is bound in the sludge and the anaerobic purification must be supplemented with an aerobic polishing step with nitrification and denitrification in order to meet the nitrogen requirement.
- *Smaller nitrogen in sludge*. Since sludge production is lower, less nitrogen will be added to the digester and therefore less nitrogen will be returned to arable land with the residue.

To be able to assess whether the alternative with anaerobic treatment is viable, practical experiments are required to see how the above-mentioned obstacles can be solved. It should be possible to find a system where most of the COD is digested and the cleaning requirements are met by a margin. However, it is not certain that increasing biogas production will justify the extra complexity that the system entails.

3.2 Biogas production plant (BPP)

In this chapter the dimensioning of the biogas process is presented together with a short description of the main components in the biogas plant.

3.2.1 Dimensioning

The dimensioning of a biogas process is based on two main parameters, organic load and hydraulic retention time (HRT). Depending on the composition of the raw material either of these will determine the size of the digester. Nitrogen load can also influence the loading rate to the digester as well as different temperature regions.

3.2.1.1 Mass balance

In Table 3 and 4 below, the mass balance is presented. Rejected products from the production processes are sometimes utilised for dilution of fibre residue from the decanter centrifuge and a small fraction of fibres is left in the waste water. It has not been possible to get accurate information of the amounts of wasted product and rest fibres. The figures in Tables 4 and 5 below are therefore estimated to 5% of the total dilution amount (normally water) and 5% of the fibre fraction respectively.

Table 4. Incoming material to the biogas production plant.

Substrate	ton/y	ton/d	%DM	%VS of DM
Fibre sludge	12 000	32,9	20	93
Waste product for dilution, estimation	250	0,7	12	98
Rest fibres before flotation, estimation	600	1,6	20	93
Primary sludge from WWTP	9 500	26	3	91
Sludge from aerobic MBBR	8 900	24,4	3	82

Table 5. Outgoing material from the biogas production plant.

Product	ton/y	ton/d	%DM	%VS of DM
Biofertilizer	28 800	79	3,8	68
Biogas, dry	2 390	6,54	-----	-----
Methane, dry	800	2,19	-----	-----
Carbon dioxide, dry	1 590	4,36	-----	-----
Water vapour saturated at 35 °C	90	0,25	-----	-----

3.2.1.2 Organic load and HRT

The organic load in a digester is defined as the amount of volatile solids (VS) that is fed into the digester volume per day. The dimension of organic load is [kg VS/m^3 digester, day]. The substrates from the wastewater treatment plant (WWTP) are diluted and this would normally result in a low organic load since the HRT would be the dimensioning parameter. In this case we mix the substrates from the WWTP with fibre sludge which has a high DM content. The result of this is that the organic load will be the dimensioning parameter. When the organic load is the dimensioning parameter a value of 3 kg VS/m^3, d is aimed at and that value is used in this calculation. The HRT will be slightly more than 30 days.

3.2.1.3 Nitrogen

Nitrogen in organic molecules is mineralised in the digester to form ammonium which is in equilibrium with ammonia ($NH_3 + H_2O \leftrightarrow OH^- + NH_4^+$). Ammonia is poisonous to the digestion processes and the concentration of free ammonia must be kept very low. The substrates in this case do not have very high nitrogen contents and nitrogen will thus not affect the dimensioning.

3.2.1.4 Temperature

A biogas process can run at different temperatures. 30-43° C is known as the mesophilic region while 43 -60° C is named the thermophilic region. The digestion rate is increased with a higher temperature, but the stability in the process is decreased and especially ammonium influence can have a more negative effect on the process. In this case a temperature of 37° C is chosen, which is a common temperature in many biogas plants.

3.2.2 Biogas plant

In figure 5 below an overview of the main parts in the biogas plant is presented.

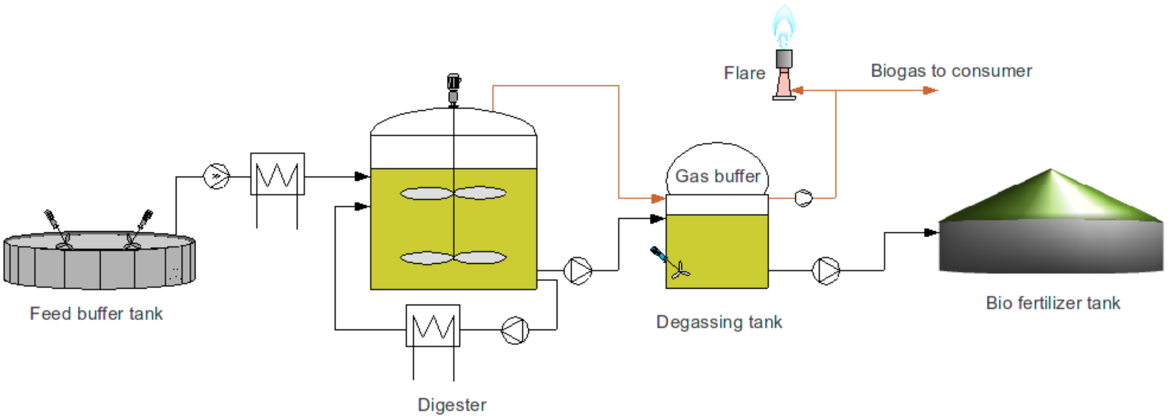

Figure 5. Main parts of the biogas plant.

3.2.2.1 Feed buffer tank

In the digestion process it is desirable to feed the digester as evenly as possible both regarding flow and composition of the raw materials. In this case fibre sludge from the production plant will be digested together with sludge from the WWTP. These flows will not be even or continuous. The fibre sludge might be fed into the buffer tank in batches. Furthermore, at maintenance in the production plant the production of fibre sludge will stop. These stops could be up to one week long and to be able to feed the digester a buffer volume is necessary. The tank will also act as a mixing tank for the different sludges. The size of the buffer tank is set to 500 m^3 which will hold raw materials for up to one working week.

3.2.2.2 Digester

There are several different types of digesters for biogas production. The choice is usually determined from type of raw material. In this case the raw material is a liquid slurry with low dry matter (DM) content and the type of digester is chosen to be a continuously stirred tank reactor (CSTR). With a HRT of 30 days the active volume of the digester will be 2 600 m^3 and the total volume 2 800 m^3 to allow for a gas head space.

3.2.2.3 Secondary digester -degassing tank

In a CSTR digester the material inside the digester has the same composition as the material that is fed out. This means that the material in the outgoing flow will continue to produce some biogas. It is not desirable to feed this material directly to a tank that is open to the atmosphere since there will be an emission of methane to the atmosphere and methane is a powerful greenhouse gas. To reduce emissions of methane the outgoing material from the primary digester is fed into a secondary digester which is closed to the atmosphere and also acts as a degassing tank. In the secondary digester the digestion will continue but at a lower rate since this digester is not heated and not insulated. When the temperature drops the gas production will decrease. The size of the secondary digester is set to 1 500 m3 to allow for good post digestion and degassing.

3.2.2.4 Gas buffer

Gas production from the biogas plant is relatively constant when the feed flow is constant. Gas consumption in a boiler is not constant since the heat demand in the production plant will vary in time. It is therefore necessary to have a gas buffer to equalise gas production with gas consumption. The gas buffer in this case is attached on top of the secondary digester. It is constructed as a double membrane dome where the outer membrane is inflated with a low air pressure and the inner membrane acts as gas buffer. This arrangement will hold the gas pressure constant and gas produced in the secondary digester will automatically be collected in the gas buffer. A gas pipe from the primary digester is connected to the gas buffer to collect the main gas production. The pressure in the primary digester will also be fairly constant with this arrangement. The active volume of the gas buffer is estimated to approximately 550 m^3 with a secondary digester with a volume of 1 500 m^3 and a height of 6 meters.

3.2.2.5 Flare

Methane is a powerful greenhouse gas, 25-30 times greater than carbon dioxide and should not be released to the atmosphere. If there is some problem with the consumption of gas, or some technical problems, the gas buffer will be filled up and the biogas must be disposed of in some way or the pressure in the digesters will increase until safety valves will open and release the biogas to the atmosphere. To avoid this, a gas flare is installed. The flare will burn the methane to form carbon dioxide. The burning capacity in the flare must be enough to burn 100% of the total gas production.

3.2.2.6 Biofertilizer tank

The degassed and cooled material from the secondary digester can be utilised as a biofertilizer in farming. Depending on the logistics for transportation of the fertilizer the demand of storage volume can vary. It can in same cases be possible to build a pipeline directly to storage on farmland, but this is not very common. In this case a storage volume of 500 m^3 is suggested. It will then have the same buffering capacity as the feed buffer tank. The fertilizer tank is constructed, and should be placed, to make it easy for tankers to collect fertilizer for transportation to larger tanks on the farmland. There are restrictions regarding what times of the year that liquid biofertilizer can be spread in the fields and buffer tanks are thus necessary.

3.2.2.7 Heating

It is important that the temperature is kept constant in the digester. Heating of raw material is done with sludge/water heat exchangers. One heat exchanger is placed in the feeding line to the digester and is the main heating unit. It can be necessary to further control the temperature, for example when there is a stop in the feeding line. An extra heat exchanger can therefore heat a circulation flow in the digester. Both heat exchangers are heated with hot water. Since the production plant is producing steam in the boiler it might be necessary to install a condenser heat exchanger to produce hot water. It is not feasible to use steam for heating since it probably will cause fouling on the sludge side of the heat exchangers.

3.2.3 Biogas production

The predicted biogas production is based on information from the food producing company and from the IVL dimensioning of a new wastewater treatment plant above. It has been discussed to utilise products that are returned to the food producer from stores, mainly due to expiration dates for the products. In this study it has been decided to not include return products since it would require a process line for unpacking of products.

3.2.3.1 Estimated biogas production

In Table 6 below the estimated biogas production from the identified raw materials is compiled. The specific production rate in Nm^3 CH$_4$/ton DM for the fibre sludge is based on a biochemical methane potential (BMP) test that the food producing company ordered in 2018 for two separate samples. The values correspond to BPM for other types of grain residues and are considered reliable. BMP for WWTP sludges is collected from the dimensioning of the wastewater plant.

Table 6. Estimated biogas production for the plant.

Substrate	Amount ton/y	%DM	Nm^3 CH$_4$/ ton DM	CH$_4$ Nm^3/y	Energy MWh/y
Fibre sludge	12 000	20	380	915 000	9 120
Waste product for dilution, estimation	250	12	405	12 000	122
Rest fibres before flotation, estimation	600	20	380	46 000	456
Primary sludge from WWTP	9 500	3	380	109 000	1 083
Sludge from aerobic MBBR	8 900	3	150	40 000	399
Total	31 250	9,9	360	1 122 000	11 180

3.2.3.2 DM (dry matter) content

The dry matter contents in the WWTP sludges are initially very low, only approximately 1,5%. This DM content is an estimate from IVL and it might be higher in reality. However, IVL does not want to be over optimistic and has decided to use the figure 1,5% DM. This would result in an organic load of only 2 kg VS/m^3, d with an HRT of 28 days. The DM content can be increased by means of gravity thickening and it would be possible to obtain a DM content of 3% with a gravity thickener. This makes it possible to increase the organic load to 3 kg VS/m^3, d with an HRT of 30 days.

3.2.3.3 Firing with biogas

Today the food producing company is utilizing natural gas as fuel in the steam boiler. The amount of internally produced biogas will not be sufficient to replace all natural gas and it will therefore be necessary to have the ability to burn a mixture of natural gas and biogas as well as pure biogas and natural gas in some periods. Thence it will be necessary to replace the existing burner with a burner with the above specifications. The burner, including auxiliary equipment, is included in the investment costs for the biogas production plant.

3.3 Life cycle cost analysis (LCC)

In this study a food producing company compared the options of:

- investing in an on-site Sewage treatment plant (Alternative A)
- investing in an on-site Sewage treatment plant and an on-site Biogas plant (Alternative B).

When all the information for an investment or action is completed, the following results are obtained:

3.3.1 Life cycle Cost, LCC

The main result of the LCC calculation is the total life cycle cost of various alternatives. The life cycle cost is calculated as the sum of the present value of all costs. In this study alternative A and B has Life cycle costs of 31.1 MSEK, and 6.56 MSEK, respectively.

3.3.2 Profitability Assessments

For profitability calculations (with repayment time or present value of investment), Alt A is assumed to be a basic alternative, which corresponds to renouncing the investment (not doing anything) or investing in conventional or existing equipment. Then the profitability of investing in Alt B is calculated instead of choosing Alt A.

3.3.3 Straight payback time

The repayment period is the number of years it takes before the higher investment for Alt B compared to Alt A has paid back in the form of lower operating costs. For the calculation to give a meaningful result, Alt A therefore needs to be the alternative that has the lowest investment cost. In this study alternative B has a payback time of 5.8 years.

3.3.4 Net present value of investment

The net present value of an investment is a measure of profitability, which is based on the same calculation principles as the LCC calculation. The net present value of an investment is the difference between the present value of the future net savings and the original investment cost. The net present value of investing in Alt B instead of choosing Alt A corresponds to the decrease in life cycle cost. An investment is deemed to be profitable if the net present value is greater than zero. In this study alternative B has a net present value of investment of 24.6 MSEK.

3.4 Sensitivity analysis

It is generally difficult to predict what will happen in the future. What is the electricity price in 5 years? Or even next year? What cost savings can you expect? Which cost of capital is realistic to expect? The more long-term measures, the greater the uncertainties. Due to these uncertainties, it may be good to make some sensitivity analyzes to see how the investment calculation is affected by different assumptions. What happens, for example, to the life cycle costs if the investment cost is

15% higher than expected? Or if the energy price deviates by +/- 10%? It can also be good to search for the "pain threshold", that is, how much the original assumptions can change without an action becoming unprofitable. How much higher maintenance costs does a company manage?

Several of the parameters used to calculate the life cycle cost have a major impact on the result, including the cost of capital, the energy and maintenance costs and the calculation period, etc. Which level one chooses influences how future costs are valued and thus also the result of the total cost. A high interest rate means that less weight is added to future costs in the total calculation. The longer the calculation period or the greater the proportion of operating costs, the greater the effect of the choice of cost of interest on the outcome. The parameters that were chosen to be included in the sensitivity analysis are compiled in Table 7, together with information on how they were varied in the analysis. The results from the analysis are then presented in tabulated form, Table 8, and in Figures 6 to 9.

Table 7. Parameters included in the sensitivity analysis and the value of respective varied parameter.

Parameter	Base-value	Low value	High value
Calculation period, facility	15 y	10 y	20 y
Interest rate	4 %	2 %	6 %
Investment cost WWTP	44.0 MSEK	39.6 MSEK (-10%)	48.4 MSEK (+10%)
Investment cost BPP	30.4 MSEK	27.4MSEK (-10%)	33.4 MSEK (+10%)
Electricity price	1 SEK/KWh	0.75 SEK/KWh	1.25 SEK/KWh
Biomethane price of the grid	0.75 SEK/KWh	0.5 SEK/KWh	1 SEK/KWh
Sludge revenue/cost	0 SEK/ton	-10 SEK/ton	10 SEK/ton
Revenue from fiber sludge	200 SEK/ton	100 SEK/ton	400 SEK/ton
Revenue Biofertilizer	10 SEK/ton	0 SEK/ton	20 SEK/ton

Table 8. Results from the sensitivity analysis on key LCC-parameters for the alternatives in the study.

Parameter	Option	Value	LCC Alt A (MSEK)	LCC Alt B (MSEK)	PT (y)	NPVoI (MSEK)
Calculation period, facility	Base	15	31,1	6,56	5,8	24,6
	Low	10	30,1	17,54	5,8	12,6
	High	20	32,5	-1,90	5,8	34,4
Interest rate	Base	4	31,1	6,56	5,8	24,6
	Low	2	30,3	-1,58	5,8	31,9
	High	6	31,8	13,17	5,8	18,7
Investment cost WWTP	Base	44	31,1	6,56	5,8	24,6
	Low	39,6	26,7	6,56	6,8	20,2
	High	48,4	35,5	6,56	4,7	29,0
Investment cost BPP	Base	30,4	31,1	6,56	5,8	24,6
	Low	27,36	31,1	3,52	5,0	27,6
	High	33,44	31,1	9,60	6,5	21,6
Electricity price	Base	1	31,1	6,56	5,8	24,6
	Low	0,75	29,7	2,87	5,5	26,8
	High	1,25	32,6	10,25	6,1	22,4
Biomethane price of the grid	Base	0,75	31,1	6,56	5,8	24,6
	Low	0,5	31,1	37,74	17,2	-6,6
	High	1	31,1	-24,63	3,5	55,8
Sludge revenue/cost	Base	0	31,1	6,56	5,8	24,6
	Low	-10	31,1	6,56	5,8	24,6
	High	10	31,1	6,56	5,8	24,6
Revenue from fiber sludge	Base	200	31,1	6,56	5,8	24,6
	Low	100	44,5	6,56	4,5	37,9
	High	400	4,5	6,56	13,4	-2,1
Revenue Biofertilizer	Base	10	31,1	6,56	5,8	24,6
	Low	0	31,1	9,76	6,2	21,4
	High	20	31,1	3,36	5,4	27,8

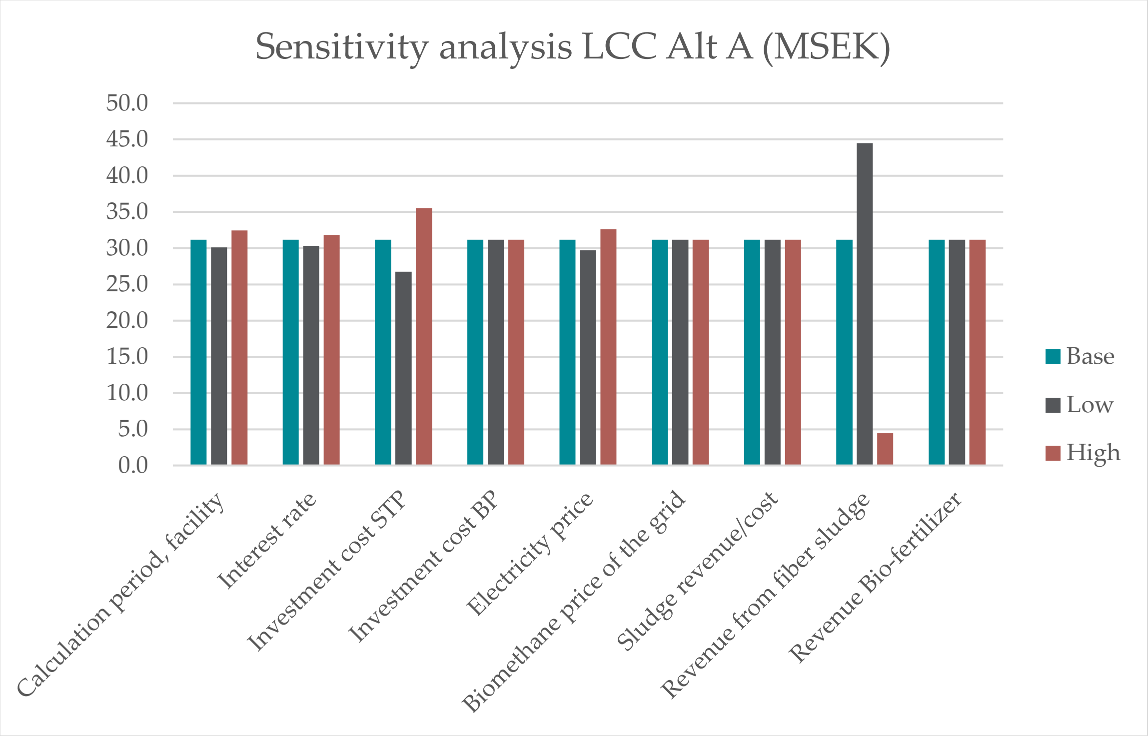

Figure 6. Sensitivity analysis of Life cycle cost on alternative A (investing in an on-site Sewage treatment plant only).

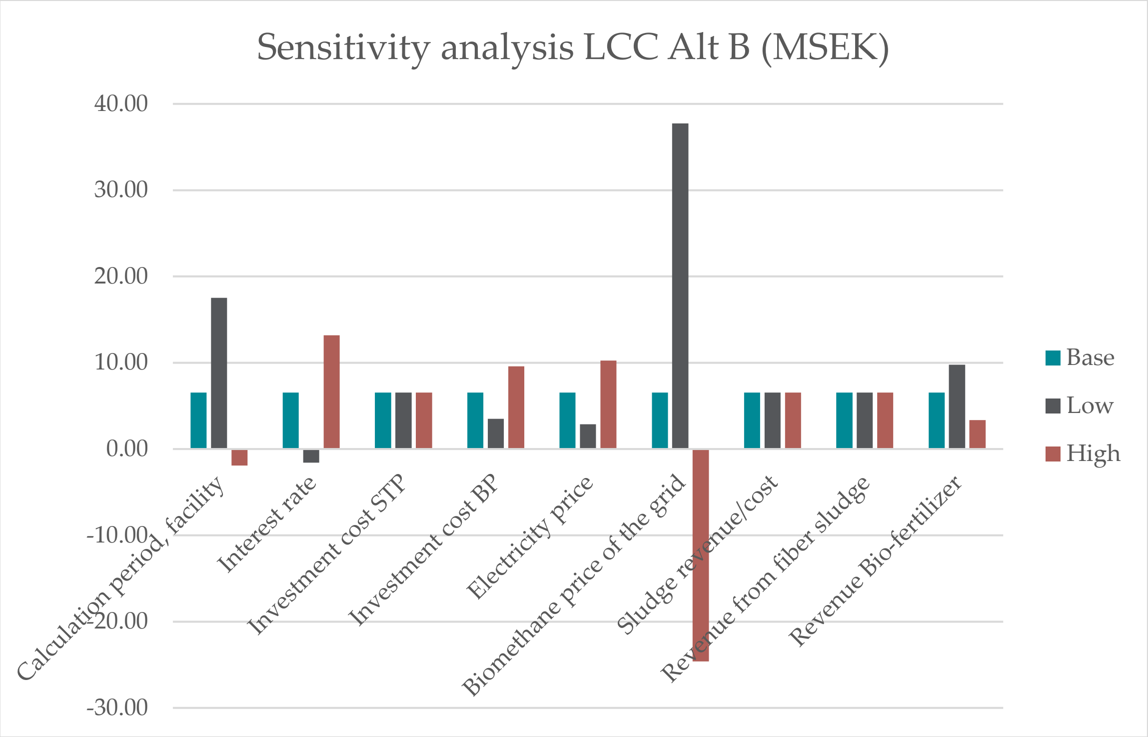

Figure 7. Sensitivity analysis of Life cycle cost on alternative B (investing in an on-site Sewage treatment plant and an on-site Biogas plant).

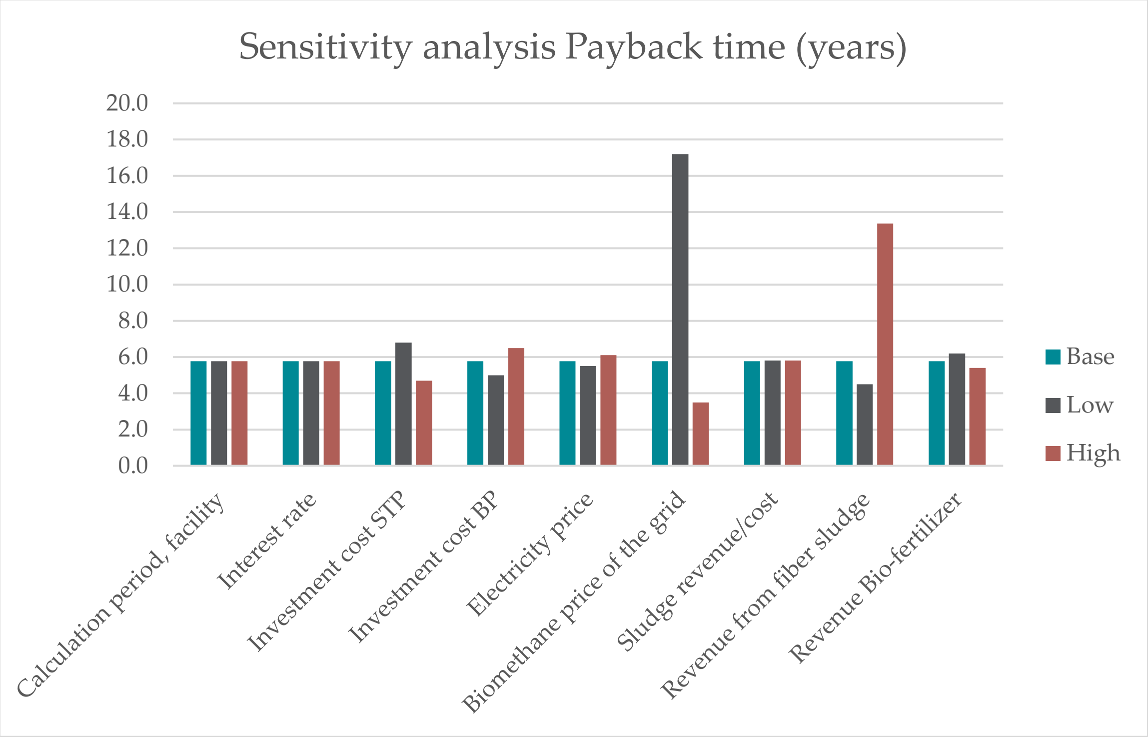

Figure 8. Sensitivity analysis of Straight payback time for choosing alternative B (investing in an on-site Sewage treatment plant and an on-site Biogas plant).

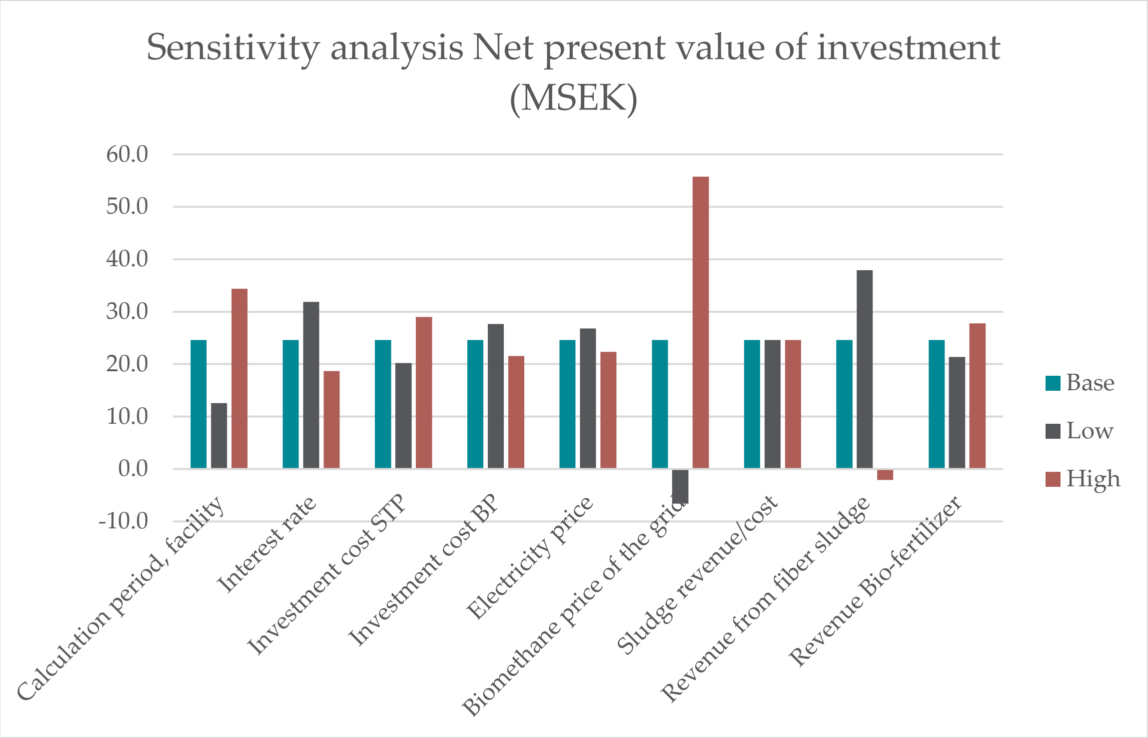

Figure 9. Sensitivity analysis of Net present value of investment for choosing alternative B (investing in an on-site Sewage treatment plant and an on-site Biogas plant).

4 Discussion

This study investigates the possibilities and consequences for a food producing company of investing either in an on-site sewage treatment facility (alternative A) or the former combined with an on-site biogas production facility (alternative B). The methodology used for evaluating these two options for the company is Life cycle cost analysis. Extensive efforts have been made when making this study to include as relevant and high-quality in-data as possible. This data has been retrieved from studies previously performed by various firms for the company and from thorough discussions between IVL and the company in the making of this study. The analysis of LCC-results can be used to determine which option is the most financial preferred from the company's standpoint, in terms of Life cycle cost (LCC), Straight payback time (PT), and Net present value of investment (NPVoI). In this study, with the base parameters used, the LCC for alternative A and B is 31.1 MSEK, and 6.56 MSEK, respectively. The PT is 5.8 years, meaning that B will make profit for the company, compared to A, after this time, in the base-case. The NPVoI for B is 24.6 MSEK, making it a profitable option of investment for the company, in the base-case. In other words, the cost for the food producing company is 31.1 MSEK for choosing alternative A and 6.56 MSEK for choosing alternative B, in the base case and over the calculation period of 15 years. This means that investing in the combination of the two on-site production facilities of sewage treatment and biogas production is much cheaper than just investing in the former of the two.

To determine how various parameters and factors influence the results, an extensive sensitivity analysis was also included in this study. As seen in table 7 above, several parameters were altered. Single parameters can have drastic influence on the results of an LCC-study and it is important to keep in mind what values were altered, and to what extent, to produce the changes in results. Four diagrams are presented in the results section showing the effects of the sensitivity analysis on: LCC for alternative A (fig 6), LCC for alternative B (fig 7), Payback time (fig 8), and Net present value of investment (fig 9). LCC for A is heavily influenced by the revenue from the fiber sludge (>±100%) and to a lesser extent by the investment cost for the sewage treatment plant, the calculation period, the interest rate, and the electricity price. The other parameters have minor to no effect. LCC for B is dramatically influenced by the Biomethane price of the grid (>±300%), heavily influenced by the calculation period and the interest rate and influenced by the investment cost for the biogas facility, the electricity price and the revenue for Biofertilizer. The other parameters have minor to no effect. The payback time is heavily influenced by the Biomethane price of the grid (>±100%), strongly influenced by the revenues from the fiber sludge, and to a lesser extent by the respective investment costs for the plants, the electricity price and the revenue from Biofertilizer. The Net present value of investment is influenced by all parameters in the following order of influence: i) Biomethane price of the grid, ii) Revenue from fiber sludge, iii) Calculation period, iv) interest rate, v) Investment cost Sewage treatment plant, vi) Revenues Biofertilizer, vii) investment cost Biogas plant, viii) Electricity price, and ix) Sludge revenue/cost. This is a measure of how important the individual parameters are for the company's decision on how to proceed with their investment plans.

All values for the sensitivity analysis were chosen carefully. However, it is very important to keep the values selected in mind when interpreting the results. The high- and low-values for the Biomethane price of the grid, for example, were varied to a rather large extent and this is in part the explanation for their strong influence on the results, if the limits would have been set narrower, the influence would also have been less dramatic. It is up to the reader to make a judgement of how they think each parameter will change in the real world, in the future and base their decisions based on that. The two most important parameters in the sensitivity analysis of this study hence are: Biomethane price of the grid and Revenues from fiber sludge. The higher the price of buying biomethane on the market, the more sense in makes to have an in-house biogas production plant. If the company chooses to try to achieve a more "vegetable"-profile the less sense in makes to sell the fiber sludge for animal feed. If the sludge cannot sold for this purpose, the revenue from it goes down and the more sense it makes to have an in-house biogas production facility.

The results presented in this study is valid for the system studied here and may have varying relevance to other more or less similar systems. According to Lindkvist et.al. residual organic streams from food industries have a high potential in being used for biogas production for internal usage in economic, energy, and environmental terms [10]. The overall resource efficiency may hence increase by utilizing these steams for biogas production and that paper suggests that other societal stake holders should have a saying in how to treat residual material from food production in the future to maximize its utilization.

5 Conclusions

The main conclusions from this work are the following:

- Life cycle cost (LCC) for alternative A and B is 31.1 MSEK, and 6.56 MSEK, respectively.
- Straight payback time (PT) is 5.8 years
- Net present value of investment NPVoI for B is 24.6 MSEK.
- Investing in the combination of the two on-site production facilities of sewage treatment and biogas production is much cheaper than just investing in the former of the two.
- The two most important parameters in the sensitivity analysis of this study are: Biomethane price of the grid and Revenues from fiber sludge.
- The higher the price of buying biomethane on the market, the more sense in makes to have an in-house biogas production plant.
- If the company chooses to try to achieve a more "vegetable"-profile, the more sense it makes to have an in-house biogas production facility.

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