DANTES
DEMONSTRATE AND ASSESS NEW TOOLS
FOR ENVIRONMENTAL SUSTAINABILITY

LCC/LCA Tools
Wet fermentation.xls
- for wet fermentation to biogas

Biogas plant with two anaerobic digesters

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ABSTRACT

This report was made within the project DANTES that is supported by the EU Life Environment Program.

This Dantes report is one in a series of five describing the LCC tools developed by ABB. The others Dantes reports are:

- DANTES - Dry fermentation.doc
- DANTES -LCP tool AX1.doc
- DANTES - LCC-LCA Battery.doc
- DANTES - Transformer.doc

A summary of the experience of developing these tools is presented in the Dantes report

- DANTES LCC-LCA tools.doc

The aim of this report is to describe the inputs and output of “Wet fermentation.xls” tool. The purpose of this excel tool is to allow designers to evaluate the cost and environmental impact of a potential biogas plant designs and do parameter studies. The biogas plant is used for biological purification of wastewater by anaerobic digestion, which encourages the natural breakdown of organic matter by bacteria in the absence of air and at the same time produce methane rich biogas.

The scope of the tool is to calculate the cash flow of the plant and evaluate the environmental impact of: different materials in the plant, emitted CO2, saving of resources (natural gas, replacement of fertilizer) and use of electricity.

The evaluation results can be used for design optimization, in market communication and sales support, showing the advantages of wet fermentation over “standard” waste water treatment.

TABLE OF CONTENT

1. INTRODUCTION

This report was made within the project DANTES that is supported by the EU Life Environment Programme.

The scope of this report is to describe the LCC/LCA tool “Dry fermentation.xls”
The purpose of the LCC/LCA tool “Wet fermentation.xls” is to allow designers to evaluate the costs and environmental impact of a potential biogas plant designs and do parameter studies. The evaluation results can be used for design optimization, in market communication and sales support, showing the advantages of anaerobe digestion of wastewater.

The scope of the tool is to try and evaluate the environmental impact of: different materials in the plant, emitted CO2, saving of resources (natural gas, replacement of fertilizer) and use of electricity and fossil fuels. The tool can also calculate the cash flow of the plant.

When the tool was developed it was expected that the inputs and the outputs would be mostly obvious to a user familiar with the dry fermentation process therefore the description of the fermentation process is minimal.

The pages (worksheets) are generally write-protected and only the yellow input fields, radio buttons and pull-down menus accept changes. The protection of pages can be removed by selecting “Protection” in the “Tools” menu in excel. The protection is only there to prevent accidental changes to functions in cells.

The plant example is used for biological purification of wastewater. The biological purification is done by anaerobic digestion, which encourages the natural breakdown of organic matter by bacteria in the absence of air and at the same time produce methane rich biogas.

Part of the produced biogas is combusted in microturbines to produce electricity and heat and the remaining biogas is combusted in a boiler to provide steam and thereby reducing the need for other energy sources, for example fossil fuel.

2. DESCRIPTION OF WORKSHEETS IN THE EXCEL TOOL

Below follows a brief description of the inputs and the results that are presented in different sheets.

2.1 Sheet: Summary

A one-page summary all plant data that have been entered to get a overview of the plant data.

Summary of data

Plant data

Feed volume: 416000 m3/year with 16 kg COD/m3
Biogas production: 0.35 m3/kg COD, methan content of biogas: 80 %
Biogas production: 2329600 m3/year, with 1863680 m3 CH4/year and 465920 m3 CO2/year.

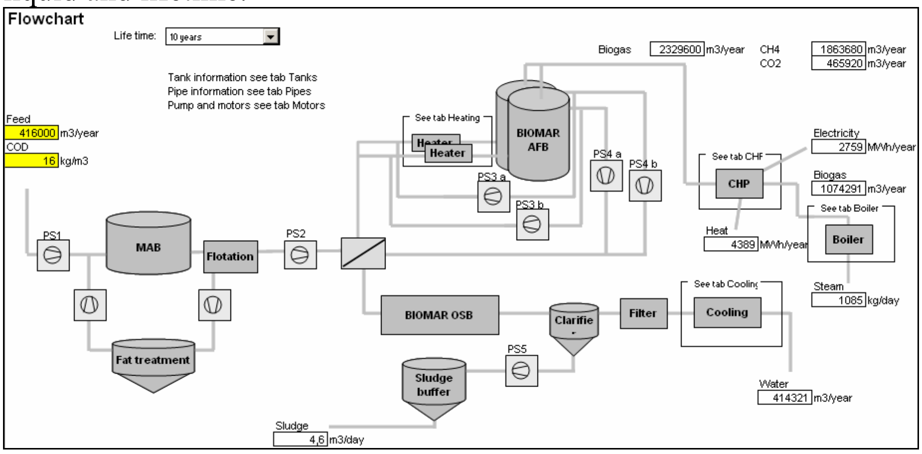
Tanks (stainless steel)

MAB: Volume 1250 m3, wall thickness10 mm.
T1 ABF I: Volume 2200 m3, wall thickness10 mm.
T2 ABF II: Volume 2200 m3, wall thickness10 mm.

Figure 1 Part of the sheet Summary

2.2 Sheet: Flowchart

Presents an overall plant description and flowchart. Expected inputs by the user are: feed volume, COD (chemical oxygen demand) content of the liquid and lifetime.



2.3 Sheet: Tanks

This tab allows the user to define the storage tanks, bioreactors, bio-towers, separators and weight of foundation. The input is used for calculating the material content of the tanks in the plant.

Tank data

Tanks of stainless steel

MAB			BIOMAR ABF I		
Volume	1250	m3	Volume	2200	m3
Hight	10	m	Hight	12,5	m
Diameter	13	m	Diameter	15	m
Material	Stainless steel		Material	Stainless steel	
Wall thickness	10	mm	Wall thickness	10	mm
Weight (steel)	52560	kg	Weight (steel)	73511	kg

2.4 Sheet: Pipes

List of pipes, their length, diameter and wall-thickness, in the plant. The input is used for calculating the material content of the pipes.

Pipes							
Pipe identification	Pipe start point	Pipe ends at	Dimension	Wallthickness	Material	Length	Weight
			Ø mm	mm		m	kg
Pump station PS 1 to MAB	PS 1	MAB	200	2	Stainless steel	50	490
MAB to flotation	MAB	Flotation	200	2	Stainless steel	25	245
Flotation to conditioning	Flotation	Cond Tank	200	2	Stainless steel	5	49
Flotation to fat hydrolysis	Flotation	Fat Hydrolysis	200	2	Stainless steel	30	294
Fat hydrolysis to MAB	Fat Hydrolysis	MAB	200	2	Stainless steel	30	294
Conditioning pump station 2	Cond	PS II	200	2	Stainless steel	5	49
Pump station 2 to HEX A in	PS II	HEX A in	200	2	Stainless steel	10	98
Pump station 2 to HEX B in	PS II	HEX B in	200	2	Stainless steel	10	98
HEX A in to Biomar A	HEX A in	Biomar A	200	2	Stainless steel	30	294
HEX B in to Biomar B	HEX B in	Biomar B	200	2	Stainless steel	30	294
Biomar A to Pump Station IV A	Blomar A	PS IVA	200	2	Stainless steel	30	294
Biomar B to Pump Station IV B	Biomar B	PS IVB	200	2	Stainless steel	30	294

2.5 Sheet: Motors

List of all the locations where a motor is needed. The user can select number of motors and effect. If one motor is installed the motor is running all the time, if two motors are installed one is running and the second is a backup, if three motors are installed two are running and the third is a backup. The used power affects the energy consumption of the plant and installed power is used for calculating the material content of motors.

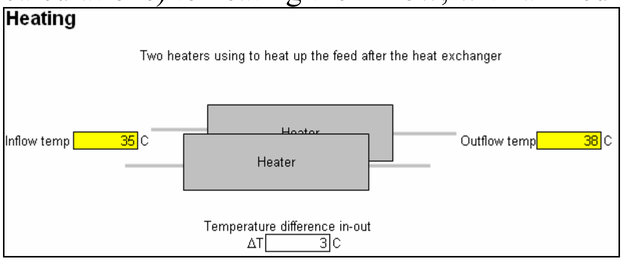
Motors/Pumps

Note: number of motors can only be 1, 2 or 3

PS1						
Number of motors	2		installed power		used power	
Effect	50	kW	100	kW	50	kW
PS2						
Number of motors	3		installed power		used power	
Effect	50	kW	150	kW	100	kW
PS3 a						

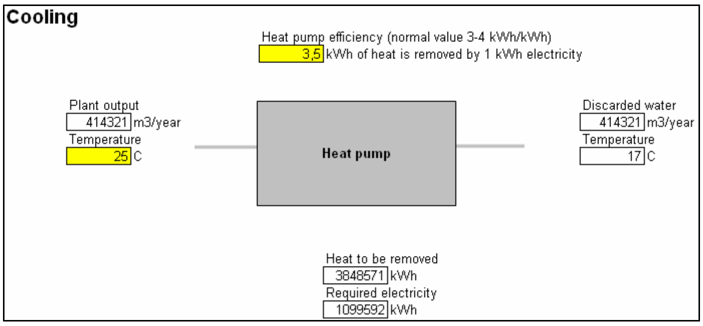
2.6 Sheet: Heating

Inflow and outflow temperatures for the heat exchangers. The heat exchanger is not modeled. The heat requirements are fixed (by other calculations) to heating the inflow, with a fixed number of degrees.



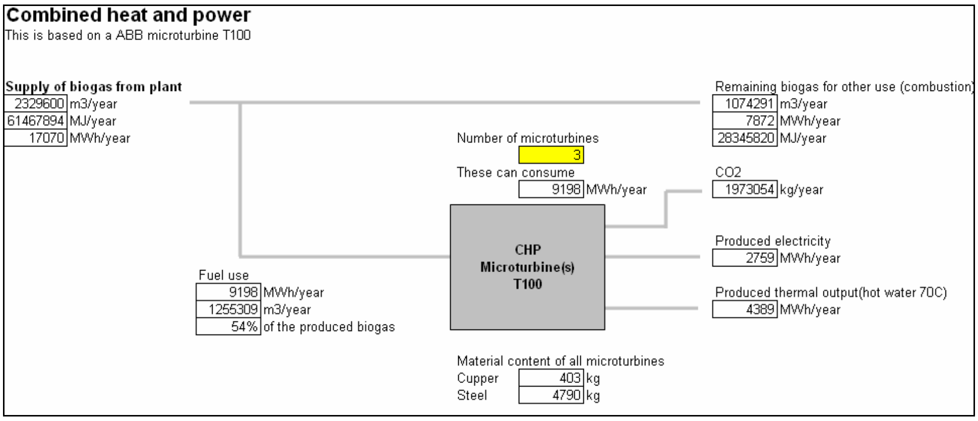
2.7 Sheet: Cooling

The discarded water might need cooling. The user can set the outflow temperature. The heat exchanger is not modeled. The heat requirements are fixed (by other calculations) to heating the inflow, and cooling of the outflow, with a fixed number of degrees.



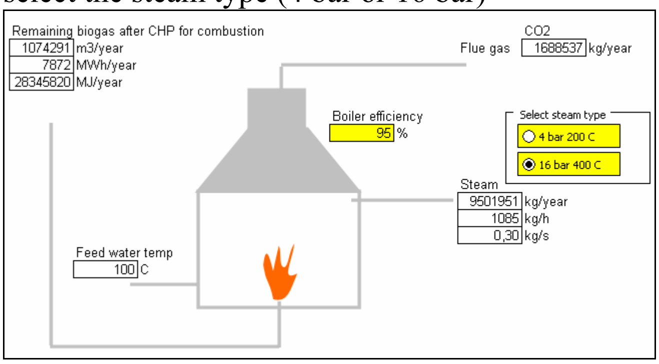
2.8 Sheet: CHP

CHP – Combined Heat and Power. On this tab some of the biogas is combusted in microturbines to generate heat and electrical power. The data for the microturbine are taken from Turbec T100 microturbine (TD D-10293.v5.pdf).



2.9 Sheet: Boiler

On this tab the rest of the biogas (not combusted in the microturbines) is combusted in a boiler to generate steam. The heat of combustion * efficiency of boiler = heat available for steam production. The user can select the steam type (4 bar or 16 bar)



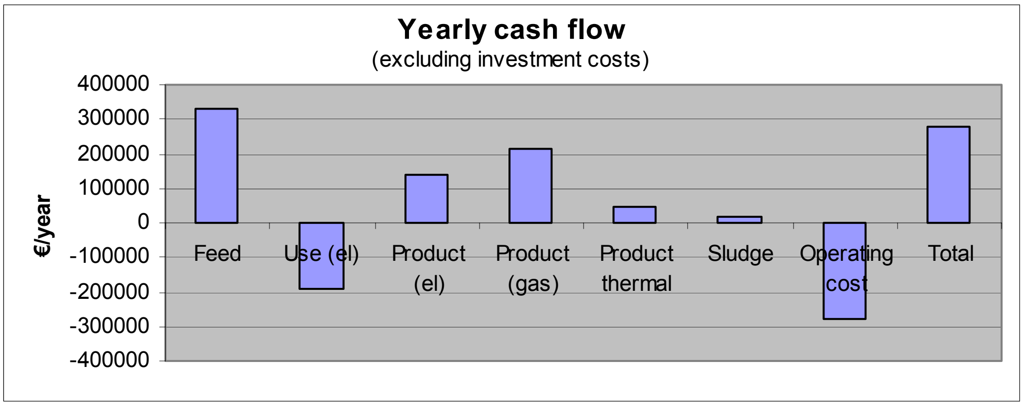
2.10 Sheet: Cost

Expected inputs in this tab are factors used for the lifecycle cost calculation, such as:

- Capital cost of plant

- Cost of feed material (can be negative if the plant operator gets paid to take care of wastewater.
- Selling price of biogas or electricity (choose one).
- Value of digested rest material (can possibly be sold as earth improvement material and/or fertilizer)
- Savings of CO2 tax from different European countries.
- Cost of additional heating of feed stream (hot water and fossil fuel)
- Cost of additional cooling of discarded process water (cold water and electricity to run the heat pump)
- Yearly operating cost of the plant, divided into fixed operating cost and salary cost of personal

If one assumes that the produced biogas is replacing natural gas, which is penalized with CO2 tax, then the saved CO2 tax should be credited to the plant Biogas is not penalized with CO2 tax.
The tab contains two graphs, one showing the size of different costs and one showing the cash flow of the plant.



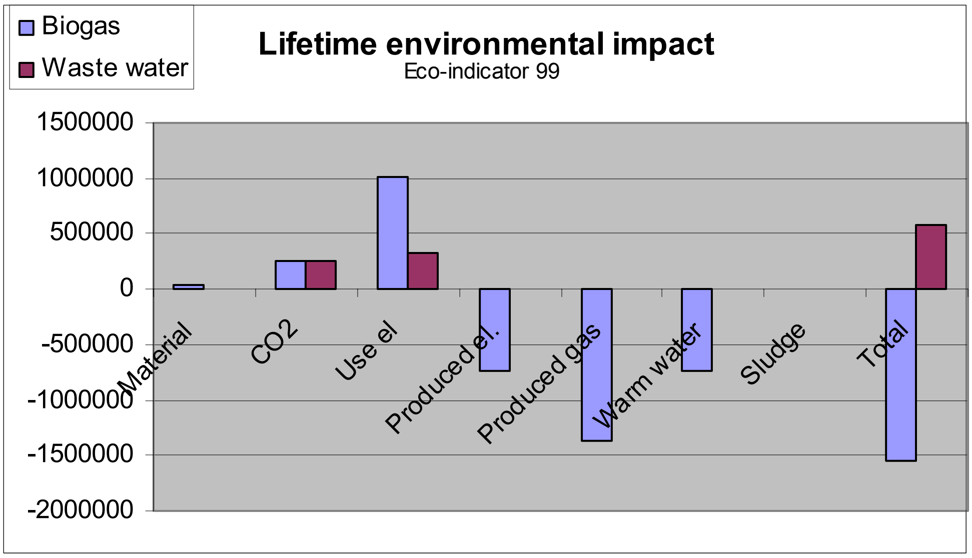
2.11Sheet: Environment

In data in this tab are factors for the environmental impact calculation. One can select classification/evaluation methods. The tool includes 5 different methods:

- Global warming potential, GWP
- Acidification potential, AP
- Nutrification potential, NP
- Eco-indicator99
- EPS2000

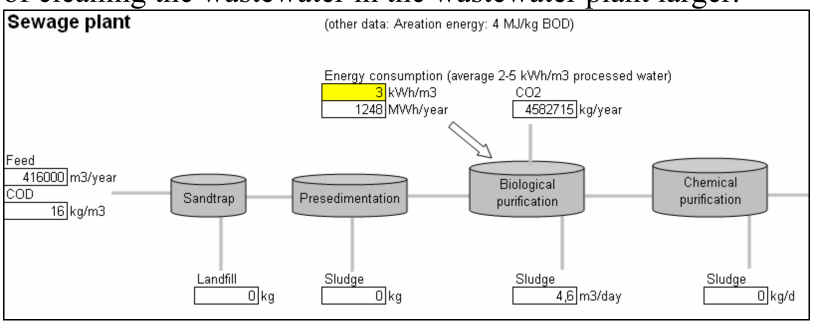
The first three are classification methods, which summarizes the impact of different emissions to specific environmental problems. The Eco-indicator99 and EPS2000 are evaluation methods, which tries to summarize the impact of emissions and resource consumption on society.
The production of electric energy generates emissions (and these emissions are different in different countries) that have to be included in the environmental evaluation of the plant. The user can select the electricity mix that the plant uses (the yearly electricity consumption is set in tab “Biogas production”)

The sludge can be used as soil improvement material and/or can be used to replace mineral fertilizer. This replaced mineral fertilizer can be credited in an environmental evaluation of the plant operation.
The user can enter how much mineral fertilizer that can be replaced by 1 kg of sludge and select four different mineral fertilizers that the sludge is replacing.



2.12Sheet: Waste water

Model of a wastewater plant used for cost and environmental comparison. The model of a wastewater plant is very simple. The only specification that a user has to enter is energy consumption/m3 treated water (average 2-5 kWh/m3). The COD (chemical oxygen demand) sets how much CO2 emission is released from the plant. The CO2 emissions of the two plants are equal (after the biogas is combusted) but since the anaerobe digestion plant produces electricity and heat, which can be used to replace fossil fuels it is more environmentally advantageous.
Since no environmental impact of the construction of the wastewater plant is included, a more detailed model would make the environmental impact of cleaning the wastewater in the wastewater plant larger.



3. BACKGROUND OF CALCULATION

This section contains the most important points and a brief discussion on calculations.

3.1 Plant components

The plant is modeled with only a few materials; Steel/Stainless steel - as construction material, Concrete - used as construction material and for the plant foundations and Copper - as electrical conductor in motors and other applications. These three materials are assumed to make up most of the plant.
The amount of a material, for example steel, is the sum of the steel content of all different components in the plant.

3.1.1 Tanks

With the volume of the tank and relationships between the sides known the measurements of a fermenter can be calculated.
With the measurements known, the surface area can be calculated and this together with wall thickness and density of the construction material the weight of the tank is known.
Tanks can be constructed from steel or cement.

3.1.2 Motors

Using the relations between output power and materials described in Environmental Product Declaration - AC machine type HXR 355 (http://search.abb.com/library/ABBLibrary.asp?DocumentID=FIEPD_3BFP000013R0101&LanguageCode=en&DocumentPartId=&Action=Launch)
A motor contains 9.4 kg steel/kW output power and 1.28 kg copper /kW output power.

3.1.3 Piping

If the wall thickness, diameter and total length of pipes is known then the amount of steel used in pipes can be calculated.
Steel in pipes = π * diameter * wall thickness * pipe length * density steel

3.2 Biogas

The production of biogas is calculated from the COD content that is removed during the process
Biogas = ((V_{feed} * COD_{in}) *0,35 = m3 Biogas

3.3 Process heat

The outflow is used to heat the inflow in a co-current heat exchanger.
When the temperature difference (ΔT) for the heat exchanger is given the temperatures of the streams can be calculated.
(ΔT = difference between hot stream in temp and cold stream out temp)
If the streams do not have the required temperature then additional heating and/or cooling is needed

3.4 Cost

Cost data are summed over the life cycle. No present value calculations of future payments are performed. The sold product from the plant can be either biogas or electricity (produced from biogas).

3.5 Environment

The environmental impacts of material are calculated with pre-evaluated datasets from the ABB database in EcoLab.
As an example, the environmental impact 1 kg of steel is shown in the table below.

Evaluation methods	Impact
AP EPD	0,1444
GWP 100 EPD	2,0905
NP EPD	0,0177
Eco-indicator 99	0,0400
EPS 2000	1,3694

Table 1 Impact of steel according to different evaluation methods

Total impact of steel = total weight of steel * impact (according to selected evaluation method)
For more information on LCA methodology see www.dantes.info

4. EXAMPLE

The plant example is used for biological purification of wastewater. The biological purification is done by anaerobic digestion, which encourages the natural breakdown of organic matter by bacteria in the absence of air and at the same time produce methane rich biogas.

Part of the produced biogas is combusted in microturbines to produce electricity and heat and the remaining biogas is combusted in a boiler to provide steam and thereby reducing the need for other energy sources, for example fossil fuel.

4.1 Model

The output of biogas (80% methane) is 0,30 m3 CH_4/kg COD (chemical oxygen demand). Part of the produced biogas is used as fuel in microturbines, which produce electricity and heat (hot water). The remaining biogas is combusted in a boiler to produce steam. The purified water has to leave the plant with a temperature less than 17C and therefore a heat pump is used to cool the water leaving the plant. The heat from the heat pump is used to warm the fresh water (to 65C), which is then warmed to 80C by heat from the microturbines.

4.2 Cost

To analyze the life cycle cost (life time 10 years) of the plant, the most significant capital cost factors where included such as plant cost and microturbine cost. In addition to these prices on process flows and energy used and produced is assumed according to table below.

Waste water treatment cost	0,9 €/m3
Cost of used electricity	0,05 €/kWh
Profit from sold electricity	0,05 €/kWh
Value of produced biogas	0,3 €/m3
Value of warm water (70°C)	0,03 €/kWh
Value of sludge	10 €/kg

Table 2 Assumed values of costs and profits used to calculate the life cycle cost.

In addition to these costs/profits there is a fixed, yearly operating cost of 50 000 € and with a need for two man-years/year (with a cost of 60 000 €/man-year) to operate the plant.

With the cost assumptions made, the biogas plant can be run with a lifetime profit as seen in the results below. The biggest cost factors over the life cycle are operating costs, use of electricity and plant capital cost. The flows generating the biggest profits are; feed cost, value of produced biogas, value of produced electricity and the value of hot water produced in the plant. The profit from the feed is equal to the cost of the alternative treatment, in a wastewater plant.

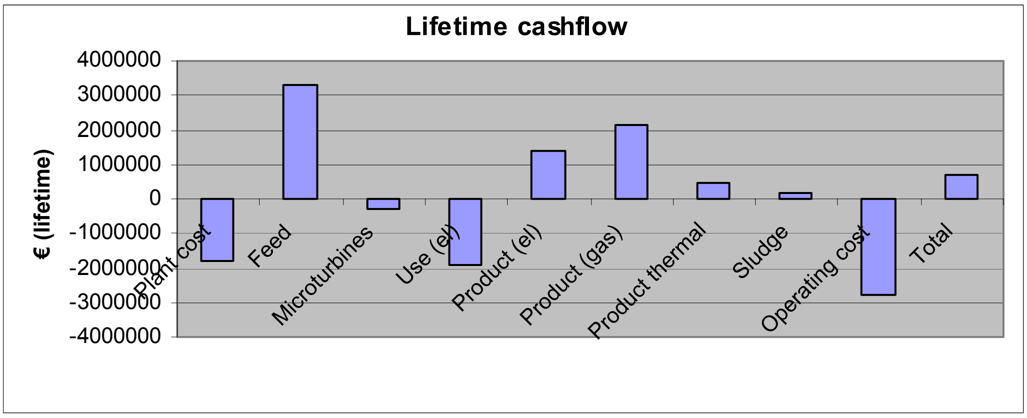


Figure 2 The lifetime cash flow (10 years) of the biogas plant (broken down in cost factors) in euro

The cost of treating wastewater in a biogas plant is lower than the current price of sending off the wastewater to external treatment.
Looking at the costs of treating wastewater in a biogas plant and in a municipal wastewater plant

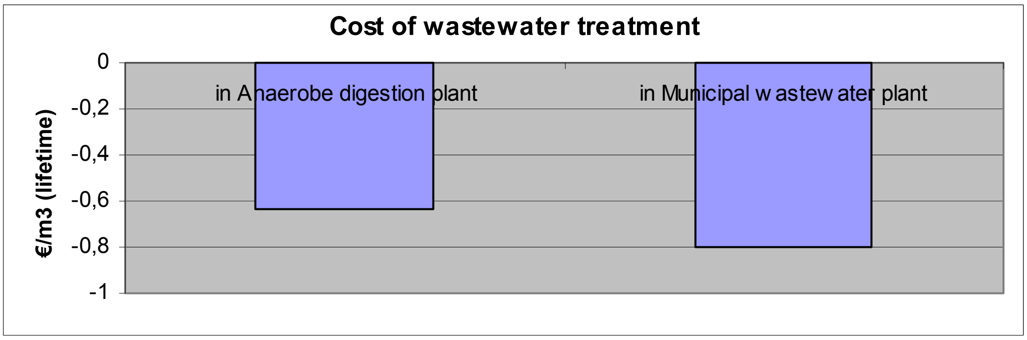


Figure 3 Costs of treating wastewater in a biogas plant and in a municipal wastewater plant in euro.

4.3 Energy balance

Input energy is electricity to run the plant is electric energy to run pumps in the plant and the heat pump and some hot water to heat the feed. CHP stands for combined heat and power and is the micro turbines.

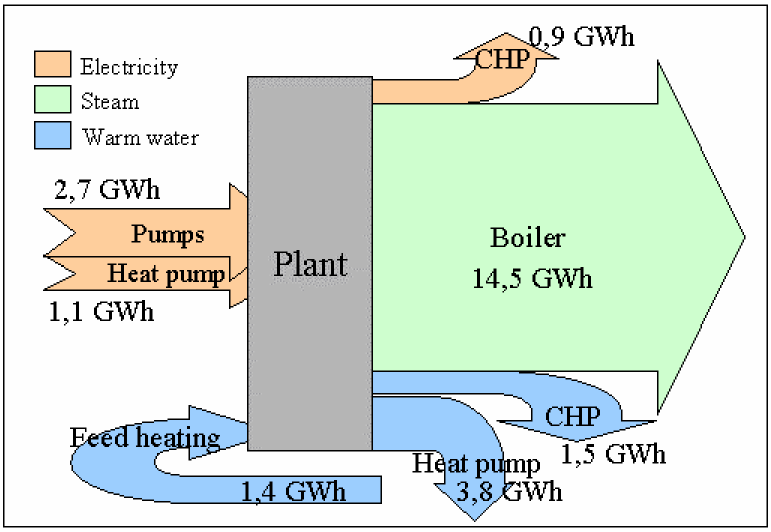


Figure 4 Heat balance of the anaerobe digestion plant

4.4 Environment

When assessing the life cycle environmental impact of plant and its operation we have to make an estimation of; the materials used in the plant, the emissions, and the energy used and produced in the plant.

The (estimated) material content of the plant

Stainless steel (tanks, pipes,...)	222 996 kg
Steel (motors, pumps,...)	7 224 kg
Cupper (motors, generators,...)	864 kg
Concrete (tanks, foundations,...)	285 977 kg

The emissions from the plant and the energy flows in and out of the plant

CO2 emissions (total)	4582714 kg/year
Used electricity (pumps and heat pump)	3815191 kWh/year
Produced electricity	2759400 kWh/year
Biogas production	2329600 m3/year
Produced hot water	4388760 kWh/year

Evaluating the materials, the energy produced and consumed, the CO2 emissions (both from the anaerobe digestion process and the combustion of the produced methane) give the following lifetime environmental impact.

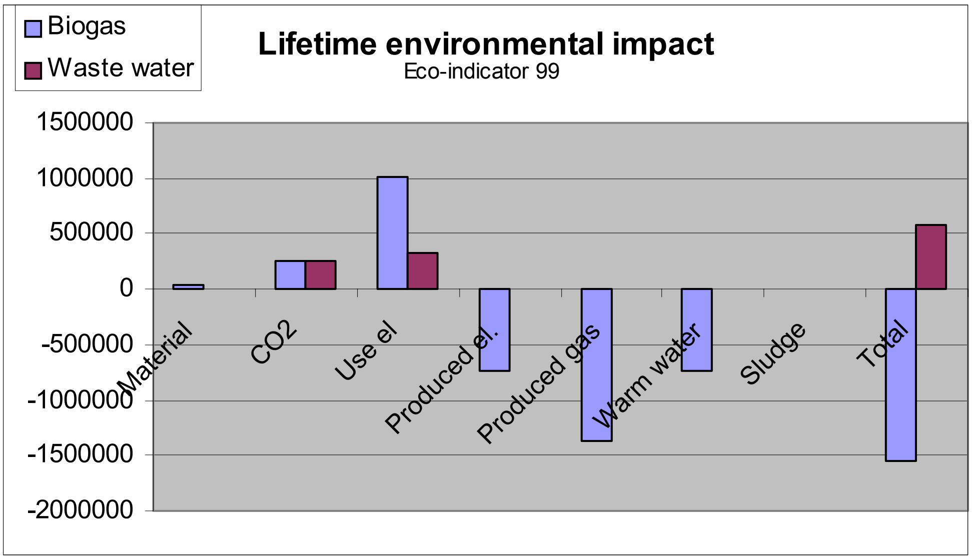


Figure 5 Lifetime environmental impact of biogas plant (compared with the impact of treating the waste water in a municipal treatment plant) according to the evaluation method Eco-indicator 99

The largest contributions to the environmental impact are the energy flows. CO2 emissions from digestion of wastewater and combustion of methane have a significant contribution to the total environmental impact. The environmental impact of materials (stainless steel, steel, copper and concrete) used in the plant is small compared to the overall lifetime impact.
If we compare the environmental impact of treating 1 m3 of wastewater in a biogas plant and in a municipal wastewater plant, one clearly sees that the treatment in a biogas plant have a positive effect on the environment and the municipal wastewater plant has a negative effect on the environment.

4.5 Environmental comparison with municipal wastewater treatment

The model of the municipal wastewater plant used for environmental comparison is simple. We assume that all the biodegradable material in the

wastewater is broken down to CO_2 and the energy need in the wastewater plant is proportional to the treated volume (3 kWh/m3 wastewater)
A more detailed model of the wastewater plant would give a more reliable comparison.

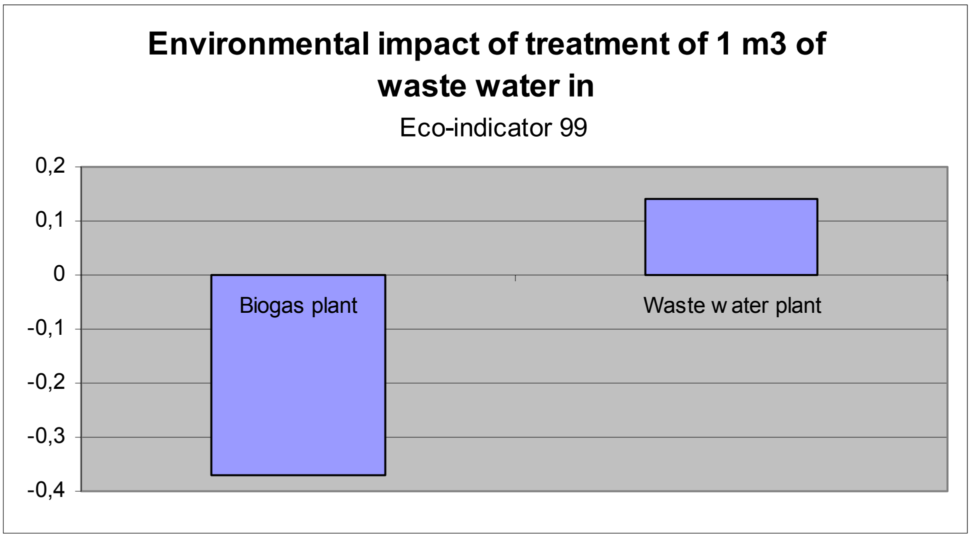


Figure 6 The impact of treating 1 m3 of wastewater in a biogas plant and in a municipal wastewater plant.

Assumptions: That the energy in hot water is needed elsewhere in the dairy so that the heat can be used to replace fossil fuel

5. CONCLUSION

The tool was used in sales communication with a dairy plant in northern Sweden and with a municipally in central Sweden but the tool is not used at ABB today since biogas applications are not presently offered by ABB.

The potential customers where interested in the result of the tool since they both had a high environmental profile. Both project are now running. Unfortunately the ABB consortia did not win the bid.