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FINAL OUTPUT REPORT – COMPARISON AND CONCLUSIONS OF PILOT B OPERATION IN LITHUANIA, ESTONIA AND SWEDEN

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a	Year
ABOWE	Project name; Implementing Advanced Concepts for Biological Utilization of Waste
AD	Anaerobic digestion
As	Arsenic
CHP	Combined Heat and Power
CH4	Methane
Co	Cobalt
Cr	Chromium
Cu	Copper
d	day
DCF	Discounted cash flow
DM	Dry matter
el.	electric
ERKAS	Estonian regional and local development agency
EU	European Union
FM	Fresh matter
g	gram
h	hour
Hg	Mercury
k	prefix: kilo
l	litre
Lt	Litas; currency of Lithuania; 1 Lithuanian litas = 0.28972 € (06.11.2014)
M	Prefix: mega
m	prefix: milli
m^3	Cubic meter
Mg	Mega gram (1000 kg)
Mn	Manganese
Mo	Molybdenum
MSW	Municipal solid waste
N	prefix: norm
Ni	Nickel
oDM	Organic dry matter
Pb	Lead
Ppm	parts per million
T	time
t	ton
th.	thermic
TS	Dry Matter
V	Vanadium
VAFAB	VafabMiljö AB – municipal owned enterprise in Vasteras
VAT	Value Added Tax

VOA/TAC	Volatile organic acids/total inorganic carbon
VS	Volatile solids
W	Watt
WP	Work package
Zi	Zinc

1. Introduction

This output report will deal with the summary of project activities related to the work package 4 (WP4) activities of the EU part financed project ABOWE (Implementing Advanced Concepts for Biological Utilization of Waste) in the time period of January 2012 till September 2014. The activities related with WP4 have been dealing with the implementation of plug flow dry digestion technology for biogas production from different waste materials.
For this purpose a pilot scale fermenter (“Pilot B”) has been operated in Lithuania, Estonia and Sweden. Each of these countries had its own specific challenges regarding the implementation of biogas technology.
An overview and comparison of the three different, country based, approaches will be given. As a conclusion, proposals for future activities regarding the implementation of waste based energy production and waste management will be given.

1.1 Summary and description of the project

All Partner regions from the REMOWE (Regional Mobilizing of Sustainable Waste-to-Energy Production) main stage project are continuing and deepening co-operation in the Extension Stage project ABOWE. In REMOWE it has been concluded that efficient instruments are necessary in partner regions to increase the rate of utilizing waste into energy.
ABOWE project covers two technologies that rise from the REMOWE project: biorefinery and dry digestion. The novel biorefinery concept was evaluated in REMOWE to have the highest innovativeness and sustainability in Finland and Estonia. REMOWE results also point out the potential to use dry digestion in biogas production. These two technologies are going to be tested in semi-industrial mobile pilot plants. The pilot plants are designed, manufactured and tested with selected waste materials from selected potential implementers/investors. The tests will provide with Proof of technology for both technologies of treating various wastes to convert them into valuable products.
The objective of ABOWE is through pilot plant tests and related activities to produce investment decision support information in form of Investment Memo for each testing region. Potential implementers and investors, such as sewage treatment plants, farms, food factories & waste management companies form the key group of ABOWE associated organisations.
After start-up and training of testing partners and other stakeholders, the pilot plants are transported to testing regions for tests there from the regions’ point of view. Testing of biorefinery will take place in Finland, Poland & Sweden; testing of dry digestion is going on in Lithuania and will be then tested in Estonia & Sweden.
The Investment Memo for each region will include Proof of technology as well as economical calculations, business plan and management plan. It will be a manual for potential implementers & investors of implementing full scale applications of the two technologies and of respective investment opportunities.
The regional model, a key outcome from REMOWE, is used to evaluate the both technologies' economical and climatic impacts from each testing region's point of view, which facilitates compiling Investment Memos.
Investment Memos will be presented in specific Investor Events in each testing region to potential implementers and investors. The objective is also to enhance willingness to invest by answering (with the information produced) to the questions that implementers and investors

are asking. These questions are listed in Letters of support, signed by potential implementers/investors (associated organizations).
Via Investment Memos & Investor Events ABOWE integrates potential implementers & investors to investments of full scale plants. The desired outcome from ABOWE are implementer/investor driven continuation projects targeting full scale investments of the two technologies.
ABOWE directly contributes to the Climate Change, Renewable Energy & Waste Management objectives of EU.
[1]

1.2 Description of the approach for full scale biogas implementation

Figure 1 gives an overview over the development of investment by onsite piloting and financial modelling for the individual stakeholder. This approach shall proof as best suitable solution to develop a full scale biogas invest.
As a first step a possible stakeholder points out which type of waste stream he wants/needs to treat. In cooperation the technologies available on the market are being observed and assessed. As soon as a conclusion regarding the technology has been found, onsite pilot testing begins.
The data gathered during piloting will then be up scaled to full scale dimensions, considering required fermenter dimensions and amount of waste streams.
This forms the basis for financial modelling and cash flow analysis, resulting in reliable data for investment decision.

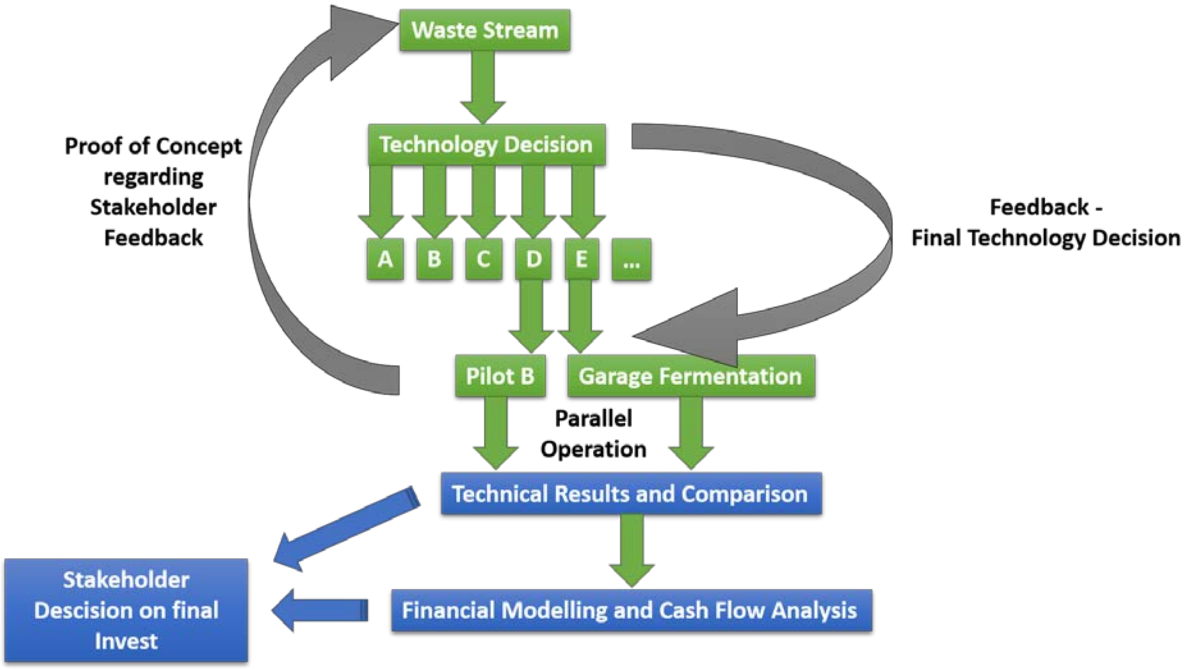

Figure 1: Approach on biogas implementation by onsite pilot testing and technical & financial modelling.

Chapter 4. describes a case study, using this approach for a full size plant for the city of Švėkšna in Lithuania.

In comparison the approach can be separated into three work packages:
- Technical (practical on-site and lab tests)
- Financial (cash flow analysis)
- Communication (development of proper communication with the stakeholders)

A description of these work packages and their methods will be given in the next Chapters (1.3 - 1.5).

1.3 Description of methods for technical work package

The technical work package dealt with all kinds of practical work. Starting from transport of the plant to each testing region, over training and troubleshooting, till evaluation of test results. This chapter will summarize the most important content of this work package.

1.3.1 Training

In the beginning of the project a training session was organized in the Ostfalia University. The aim was to get to know the starting and operation of different anaerobic digestion (AD) systems, including the different phases of the AD process. Furthermore the evaluation of different substrates for biogas production and the determination of different parameters for process and substrate evaluation (DM, oDM, NH_4-N, VOA/TAC, pH, CH_4-, CO_2-, H_2S-concentrations, concentrations of organic acids).
The training also involved an excursions to a full-scale dry digestion plant and to Pilot B in Germany.

The objective of that training was to acquire the following skills and competencies:
- to take samples and to do the necessary test
- to interpret the analysed parameters in the way to recognize that the process is stable
- to run Pilot B and to be able react on troubles independently

The operation of the plant in Lithuania, Estonia and Sweden can be considered as a part of the education of the involved local players like the operator and the direct environment.
The idea of this part of the training was, that the operator acquires the skills:
- to start the process of anaerobic digestion
- to run pilot B and
- to get an idea of how to run a full scale plant.

1.3.2 Substrate evaluation

Substrate evaluation regarding their biogas potential is a crucial part of planning and running a biogas plant. As the substrate or the substrate mixture mostly defines the biogas output of a fermenter, it is advisable to evaluate the input material in fermentation tests

Dry matter (DM)/ organic dry matter (oDM, VS) content

The DM/oDM content of the substrate helps to determine the share of the material that can be converted to biogas. Furthermore it is needed to calculate the loading rate of the fermenter. These tests have been run according to VDI 4630 guideline (see [2]).

Biogas potential by batch tests

The biogas yield test (according to VDI 4630) determines the digestion behavior and the gas formation potential of substrates within a measurement period of 30 days.

In principle a very high gas yield is desirable. But if the conversion is too rapid this can lead to an overloading of the fermenter. On the other hand a slow degradation leads to long residence times and a possibly incomplete conversion of the substrate. [2]

Long term continuous tests

In addition to the batch tests, long-term continuous tests have been operated. In order to determine inhibitions in the AD process, these tests have been operated in parallel to the respective manor as the pilot plant. This also allowed better comparability of the biogas yields of the pilot plant with the expected yields determined in batch and continuous tests. [3]

1.3.3 Pilot B on-site testing

The pilot plant is designed for long term continuous operation to estimate the biogas potential of various substrates using the principle of plug-flow dry digestion (see Figure 2). Due to its size, real size material (as it would be used in full scale plants) can be used. This allows the process simulation of full-scale biogas plants. [3]

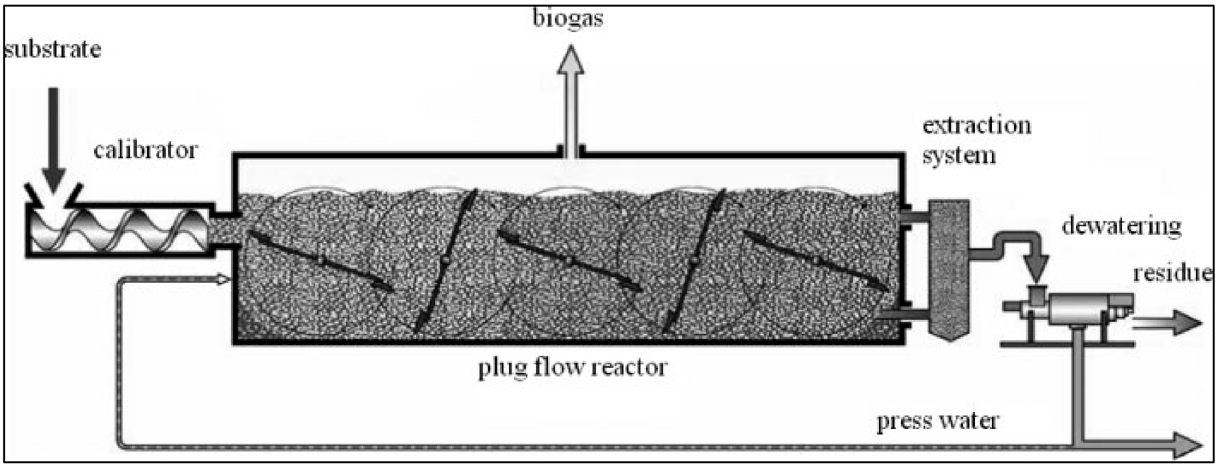

Figure 2: Process flow diagram: plug flow fermenter (STRABAG, 2012, adapted)

The pilot plant is also equipped with all necessary lab material to estimated process relevant parameters (see Figure 3).

With its possibilities it can be used as a training device for future plant operators, as a research facility for biogas issues as well as a demonstration object for interested people.

Figure 3: Interior of Pilot B Container. Left side: Laboratory, plant steering and measuring equipment. Right side: fermenter with technical equipment.

The main objectives of the work with Pilot B were:

- Determination of stable and effective conversion of local available waste to biogas
- Examination of digestate regarding accumulation of harmful substances (e.g. heavy metals)
- On-site training of local staff
- Demonstration of dry digestion technology to stakeholder and interested local people
- Proof of concept of dry digestion technology for biogas production from waste material

1.3.4 Data preparation from test runs

The results from pilot-, batch and continuous tests have been prepared to receive information on upscaling parameters. Especially the reachable biogas yields have been an important information, as they had a crucial impact on the economic calculations (see Chapter 1.4).

1.3.5 Technology upscaling to full-size plants

On the basis of local available waste amounts and results from pilot testing, calculations for full-scale plants have been performed. This data also influenced the economic calculations.
In the following an exemplary calculation will be given.
Some assumptions for the calculation are given in Table 1.

Table 1: Assumptions for up scaling calculations of a full scale plug flow dry digester.

Available substrate (MSW pre-sorted) for plug flow digestion	24,000 Mg/a (FM)
Estimated VS(%FM) of the MSW	34%
Methane yield plug flow digester	75 Nm^3/Mg (FM)
Organic loading rate of the plug flow digester	8 – 10

The estimated methane productivity of MSW makes it possible to calculate the producible volume of methane:

$$V_{CH4} = m_{MSW} * \eta_{CH4\,per\,Mg\,MSW} = 24{,}000\ \frac{Mg}{a} * 75\ \frac{Nm^3}{Mg\ (MSW)} = \underline{1{,}800{,}000\ \mathrm{Nm}^3 (CH_4)}$$

The assumed organic loading rate of 8 kg (oDM)/m³*d for the fermenter, as well as the organic dry matter content of the substrate (34% of FM) allows to calculate the necessary fermenter volume:

$$V_{fermenter} = \frac{m_{manure} * w_{oDM}}{oLR * 365\ d} = \frac{24{,}000\ Mg * 0.34\ m^3 * d * 1{,}000\ kg\ a}{8\ kg(oDM) * 365\ d\ a\ Mg} = \underline{2{,}794.5 m^3}$$

The assumed organic loading rate of 10 kg (oDM)/m³*d for the fermenter, as well as the organic dry matter content of the substrate (34% of FM) allows to calculate the necessary fermenter volume:

$$V_{fermenter} = \frac{m_{manure} * w_{oDM}}{oLR * 365\ d} = \frac{24{,}000\ Mg * 0.34\ m^3 * d * 1{,}000\ kg\ a}{10\ kg(oDM) * 365\ d\ a\ Mg} = \underline{2{,}235.6 m^3}$$

If two fermenters would be run in parallel operation, this could result in a fermenter size of approx. 1,500 m³ each. It would allow flexibility for more substrate or a lower loading rate. Should sanitation be an issue, the parallel operation could ensure a sanitation effect in thermophilic conditions. In this case the two fermenters would have to be fed/extracted with a 24h delay for proper sanitation time guaranteed.

Table 2: Assumptions made regarding up-scaling calculations.

Full load operating time CHP unit	8,760 h/a (7,900 – 8,200 h/a realistic)
Electric efficiency CHP unit	40% (100 kW)
Energy content methane	9.97 kWh/m³
Organic loading rate fermenter	3 kg(oDM)/m³*d

The calculated biogas volume allows the calculation of a suitable CHP power. Some more assumptions can be found in Table 2.

$$W_{available\ from\ CH4} = V_{CH4} * W_{CH4} = \frac{1{,}800{,}000 Nm^3}{a} * 9.97 \frac{kWh}{Nm^3} = 17{,}946{,}000\ kWh/a$$

With the assumed efficiency of the CHP unit we get the power that can be generated:

$$W_{generated\ by\ CHP} = W_{available\ from\ CH4} * \eta_{CHP} = 17{,}946{,}000 \frac{kWh}{a} * 0{,}4 = 7{,}178{,}400\ kWh$$

With the annual runtime of 8,760 h/a (which would mean nonstop operation) the possible power of the CHP unit could be:

$$P_{CHP} = \frac{W_{generated\ by\ CHP}}{t_{runtime,CHP}} = \frac{7{,}178{,}400\ kWh\ a}{8{,}760\ h\ a} = 819\ kW$$

If repair work and maintenance is taken into account, the power of the CHP unit could be higher, due to shorter runtime. [4]

1.4 Description of methods for financial work package

For planning the construction and implementation of a biogas plant many aspects have to be taken into account. Among technical aspects especially the economic aspects are significant for the implementation of biogas technology.

Especially those factors which affect an influence on the cash flow have to be taken into account. These factors are the sourcing and sales markets, operating costs, financing conditions and also influence quantities of the public sector. [5]

In the following the possible cost factors of biogas plants of different sizes and noticeable biogas plant characteristics concerning the size of the plant and the substrates which will be used as input materials are specified.

It is also of importance to consider the risks which occur at these factors. In any case the most important factor when implementing biogas technology is to assure safe substrate availability. The biogas plant has to be supplied with material during the whole year. Also the use of the produced energy either the conditioned biogas itself, resulting heat or the electric energy generated by CHP unit has to be assured.

1.4.1 Cost factors

Besides investment costs for the building of the biogas plant there are operational costs (both in extracts):

Investment costs:

- Engineering, permission of the authority, connection to the public grid
- Functional units (substrate delivery and pre-treatment, digester, gas storage, biogas treatment, CHP unit, pumps, piping, offices, land costs, digestate storing, vehicles and others)

Operational expenses:

- substrate costs, analysing costs, process energy, consumables, maintenance and repair
- Purchased services and goods: analytics, fresh water, waste water, diesel for wheel loader
- administrative and labour costs
- Service contracts and Insurance
- Operational costs for the upgrading facility
- Own electricity and heat demand
- Costs for transport and disposal of digestate

The digestate of the planned process probably has to be disposed. Therefore additional operating costs (e.g. for incineration) have to be considered.
Moreover it has to be kept in mind that a biogas plant does not work economically in the start-up phase because the biogas production starts gradually (start-up phase dependent on substrate up to 6 month). [4]

1.4.2 Specific investment costs

Dependent on the size of the biogas plant especially the specific investment costs are varying. In Table 3 specific investment costs are listed:

Table 3: specific investment cost related to biogas plant size [6]German literature source)

Size of biogas plant	**Specific investment costs**
75 kWel	ca. 9,000 €/kWel
150 kWel	ca. 6,500 €/kWel
250 kWel	ca. 6,000 €/kWel
500 kWel	ca. 4,600 €/kWel
750 kWel	ca. 4,000 €/kWel
1 MWel	ca. 3,500 €/kWel

Comparing the specific investment costs it is remarkable that the bigger the size of the plant the lower the specific costs for the investments. Therefore the possible investor has to consider very carefully which size of the biogas plant would be profitable.

Considering theses prices it has to be taken into account that they represent full equipped biogas plants. For any costs which may arise e.g. concerning the biogas conditioning or the pre-treatment of the substrate there are some savings (or additional costs) possible (depending on the substrate and the use of the produced biogas there are possibly some plant components unnecessary or additionally necessary).

These amounts are key values for the calculation of average investment costs of biogas plants. They were determined by investment costs for different German agricultural biogas plants. When thinking about special requirements concerning the operation of biogas plants as the use of for example municipal solid waste in garage fermenters there might be adjustments and modifications necessary. That could be additional costs for pre-treatment of the substrate. Apart from that a CHP-unit might not be necessary, because there will be no production of electricity but the use of conditioned biogas as fuel. That means the costs for the upgrading of the biogas have to be considered. [4]

Here the specific investment costs for biogas plants with biogas upgrading are listed.

Table 4: economic key figures concerning investment costs for biogas plants [11].

Size of biogas plant	**Specific investment costs**
Biogas plant with biogas upgrading 400 Nm^3/h	ca. 9,600 €/Nm^3*h
Biogas plant with biogas upgrading 700 Nm^3/h	ca. 9,100 €/Nm^3*h
Biogas upgrading facility	
400 Nm^3/h	3,600 €/Nm^3*h
700 Nm^3/h	2,400 €/Nm^3*h

Definition of farm/small scale and large scale

First of all the different sizes of biogas plants which will be considered in this paper have to be settled. When we think about farm scale biogas plants a size of < 25 kW is being considered, large scale biogas plants have a size of about 500 kW and full scale plants more than 500 kW.

As a rule of thumb it can be considered that for 12 to 15 m^3 biogas production per day 1 kW CHP-power has to be assessed. The investment costs for a CHP-unit (power range 15-250 kW) are between 500 and 750 € per kW (German data base) installed electrical capacity. [5]

Considering large scale or full scale biogas plants and especially regarding the handling of household bio waste it has to be taken into account that bio waste demands a special treatment. Especially the sanitation of the material is a necessary demand. The sanitation of biowaste which is used for anaerobic treatment is regulated by EU-hygiene regulation (VO 1774/2002/EG) [7]or German Biowaste Ordinance (BioAbfV) [7]. Thus bio waste has to be sanitized for example by heating it up to 70 °C for one hour.

Thus it has to be taken into account that the investment costs for biogas plants using biowaste as substrate are about one third higher than for biogas plants using for example renewables (see Figure 4).

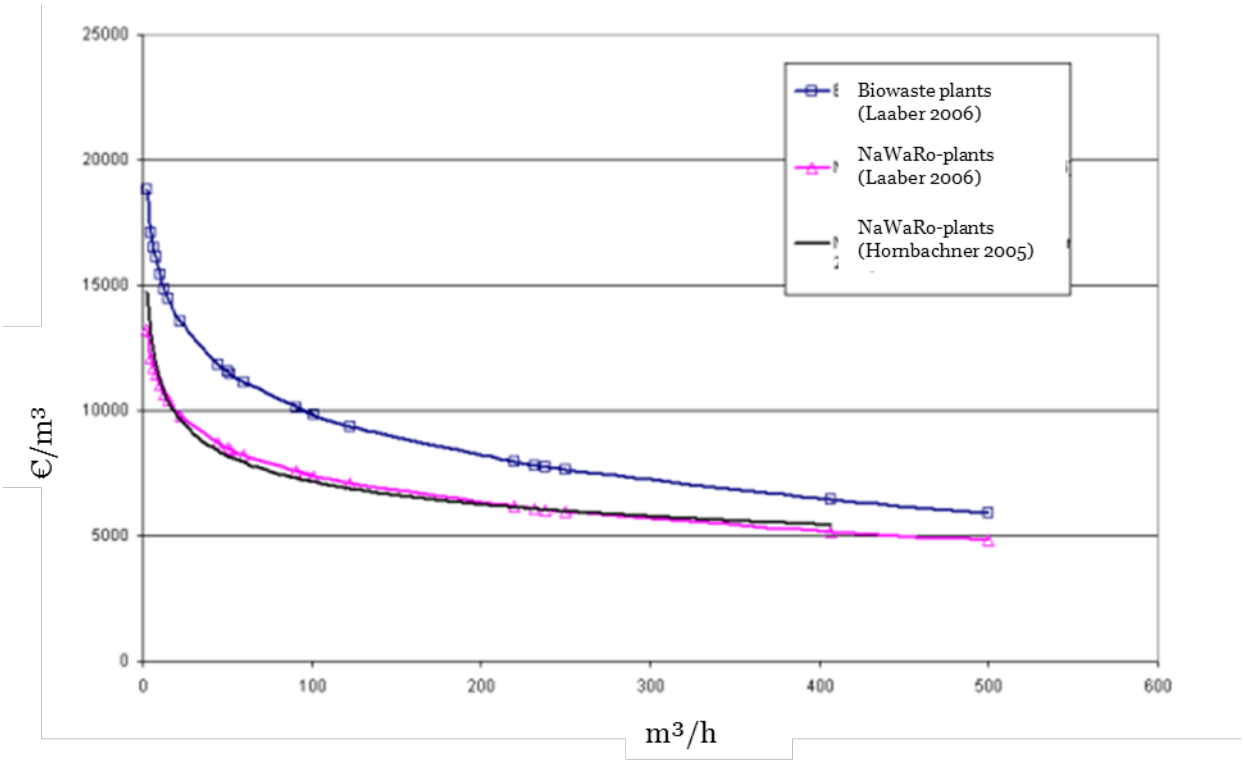

Figure 4: specific investment costs (without CHP and biogas processing in €/m^3 related to size of biogas plant (m^3/h) [8]

Nevertheless the specific investment costs tend to decrease with the larger sized the plant capacity is. Identifying the different groups of the investment expenses it makes obvious that part of the costs for planning and construction are personnel expenses. They should be considered separately, because there are considerable variations in the different countries.

Regarding the investment costs the biogas technology can be divided into several functional units (see also Table 5).

Table 5: Cost items of a biogas plant.

Investment costs		
Phases of the planning and construction of a biogas plant		Engineering
		Administrative permission
Construction phase	Construction work, personnel costs	
	Functional units	Substrate storing and pre-treatment
		Substrate delivery
		Main digester
		Secondary digester
		Gas storage
		Biogas treatment
		Flare
		CHP unit
		Pumps and stirring technology
		Piping
		Office building
		Control unit
		Grid connection
		Land costs (road, fence and other
		Digestate storage and conditioning
Start-up phase		External expertize
		Machines and vehicles
Operational expenses		
Maintenance and repair		**Share of acquisition value in % (per year)**
	Substrate storing and pre-treatment	2
	Substrate delivery	5
	Main digester	1
	Secondary digester	1
	Gas storage	1
	Biogas treatment	1
	CHP unit	0,013€/kWel

	Pumps and stirring technology	5
	Piping	1
	Office building	1
	Control unit	1
	Grid connection	1
	Land costs (road, fence and other	1
	Digestate storage and conditioning	1
	Substrate costs	
	Analysing costs	
	Process energy	
	Consumable supply (including ignition oil)	
	Output costs	
	Variable costs of vehicles	
	Variable costs of machinery	
	Fuel for machinery	
	Staff (wages and travel)	
	Insurance	
	Others (rent, current assets, fees, miscellaneous)	

The major investments here are the digester, gas storage and CHP unit whereas components such as office buildings, substrate storage, pump and piping technology have a smaller share. Basically the components which include high technology have higher influence on the overall costs.

Nevertheless it has to be taken into account that some parts of the biogas plant have to be reinvested regularly because of a short operational life span such as pumps, stirrers and also the CHP unit. Therefore the lifetime of pumps is considered to be 4 years, of CHP units about 6 years. [9]

1.4.3 Operating costs

In general the specific operating costs of a biogas plant are higher the smaller the biogas plant is. There is a decrease of the specific costs with the increase of the size of the. Especially the operating costs for a biogas plant using biowaste are higher than the costs when using renewable raw materials. The lowest operating costs occur when using manure (without consideration of the substrate costs). [8]
Nevertheless it has to be considered, especially for full scale biogas plants, that substrates with a high energy potential should be used, so that costs and effort for transport are minimised.

Considering the economy of a biogas plant it has also to be regarded that between 5 to 20% of the electrical energy produced by CHP technology (this amount has to be drawn from the public network) are used for own requirements of the biogas plant (pumps, stirrer and others) The heat of the CHP unit can be used for the heating of the fermenter (heat demand biogas plant: 5-25%). [8] So, if the feed-in tariffs of the produced electricity are higher than the prices for the electricity it might be economical to sell all of the produced energy and buy the needed energy from the national energy supplier. [10]

Referring to the operational expenses can be divided into variable and fixed expenses. Here the substrate costs may be up to 50 % of the total variable expenses depending on the kind of the used substrate and required transport . [11]

Considering the operating costs of biogas plants, costs for maintenance and repair have to be charged for the whole amount. The expenses are depending essentially on the components. In Table 5 the estimated shares on the expenses in percentages as share of the purchase price are listed. According to this list the highest expenses (proportionally) for maintenance and repair are caused by pumps and stirres. Here the expenses for the CHP unit are estimated to be 1.30 €ct/kW_{el}. [9]

If biogas is conditioned to biomethane a CO_2-elimination is necessary. Therefor costs of about 1.35 €ct/kWh arise. [12]
For maintenance a yearly amount of about 6% of the one-time investment costs can be assessed. [13] (see also Figure 5)

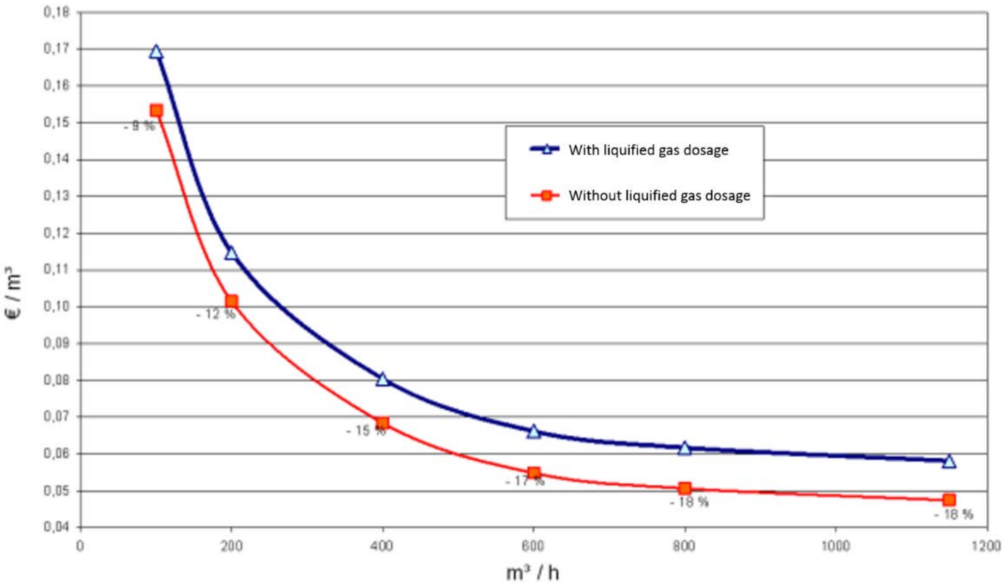

Figure 5: operating costs with and without liquefied gas dosage by pressure water scrubbing dependent on the plant size [16].

For biogas plants operated in Germany costs for maintenance can be estimated to be at 2.5 €cent/kWh (including a reserve for replacement investment, e.g. CHP general overhaul after 6 years). [14] Lab analyses are necessary for supervision of the biogas process. Therefore six analyses per digester and year are proposed as a guideline. [11] In Germany the expenses for one analysis is approximately 150 €.

1.4.4 Personal costs

One significant cost item of the operating costs is the personal costs. Especially the treatment of biowaste requires more working time and has to be taken into account.

Figure 6 shows the dependency of the required working time on the power of the installed CHP unit. Here also the required time for troubleshooting is considered. The higher the nominal capacity the higher the total required working time for supervision of a biogas plant, but the more automated the biogas plant is, the less personal is needed. However the specific required working time decreases the higher the installed power of the CHP unit.

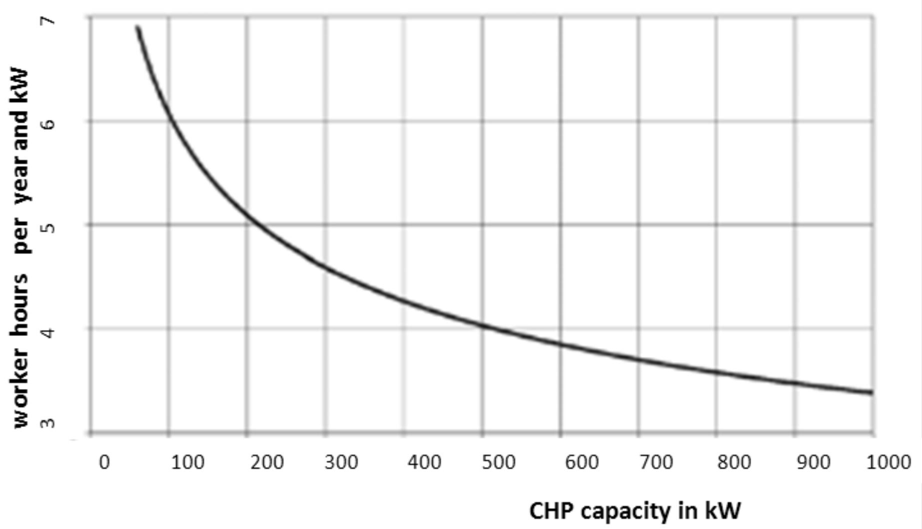

Figure 6: specific required working time for plant supervision and maintenance [15]

Considering the required working time it is obviously that it is very important to notice that for a small scale/farm scale plant there is already one person required (though it is just few hours per day) caring for the biogas plant. In case of a biogas plant with 500 kW CHP unit a worker needs about 2000 hours per year for maintenance.

It also has to be taken into account that the use of biowaste causes a higher amount of working hours for maintenance. As there was a constant development ongoing during the whole project, additional key figures (from existing German plants and from literature) have been added. Please refer to Table 18 in Chapter 3.2 for the latest numbers. [4]

1.4.5 Revenues

Generated revenues of a biogas plant can be:

- Sale of electricity
- Sale of heat
- Sale of gas
- Sale of digestate

Usually there is no risk for the sale of electricity. The payment of the electricity depends on different factors especially the regulations of the government concerning the feed-in tariffs. The sale of heat constitutes among others the problem that the heat consumers have different seasonal demands.

Therefore the sale of the produced gas by upgrading and feeding it into the grid presents a suitable possibility. However the upgrading of the biogas is only suitable for bigger sized biogas plants, because of the high investment costs. Moreover a suitable gas grid has to exist. [4]

1.5 Description of methods for communication work package

During its journey the strategy of communication had the national and regional stakeholders in focus. To inform them and to ensure their engagement with the aim to foster investment into dry digestion technology a strategy of communication had been implemented, that includes elements of:

- Marketing strategies
- Change processes
- Education strategies

1.5.1 Stakeholder Identification

Marketing defines, that the media and the ways, which are used to inform and persuade possible buyers has to be chosen under consideration of the target group, which is in this case the group of stakeholders. [16]

Responsible for the selection and naming of the stakeholders was the regional partner, which had the best insight into which person, which organisation and which association absolutely had to be involved.

Leading questions for identifying stakeholders have been:

- Who is affected by the results of the project?
- The area of responsibility of which institution is affected?
- Which people with influence are interested in the technology?
- Which inspection authorities have to be involved in the decision process?
- Which institutions are able and willing to invest money into new technologies?
- Which people of the personal network of the local project partner could be involved?
- What could be an obstacle?
- Who has a problem that could be solved by the technology of anaerobic dry digestion?

The more the identified stakeholders are affected by the topic, the better the personal relationship to the inviting local partner the more likely is, that the invited people will attend and actively participate. [4]

1.5.2 Local partners

From the communicative point of view the local partners are designing the way of communication in the country, they bring in their personal and professional network as the source of all activities regarding presenting and representing the project.

1.5.3 Media

The following media has been used:

Internet

The newsletter and all reports have been published on the ABOWE web site (www.abowe.eu).

Newsletter

Using the template of the ABOWE project a national newsletter edition has been established. The newsletter´s impact on the external stakeholder has not been measured but it can be considered as one successful part of the stakeholder management. The strong impact for the internal stakeholder can be shown, due to the direct experience of the reporting team.

The used newsletter was a mixture of old style and new media. It is available as hardcopy and can be sent by mail. It is published on the project´s web site, it has being sent via email and it could be posted on social media.

Three newsletter were published during the period the pilot B had been in Lithuania, and one Newsletter each in Estonia and Sweden. The newsletters in Lithuania and Estonia were available in English and in the local language. The content of the newsletters was focused on the results of the WP 4 activities. (See national Output reports) [3] [17] [4]

Impact

The internal impact of the newsletter was perceivable especially in the days before the final editing. To fix the content and to write short articles it was obligatory that the agreements between the partners were clear and that everybody knew what to do. Intensive discussions accompanied the editing process of each newsletter that created security and clarity for the partners.

Events

On-site events were organized during the stay of Pilot B in every testing site with the aims:

- To inform
- To activate
- To come into contact
- To learn

Stakeholder events

Stakeholder events were planned and realised in every country running Pilot B. The main objectives of these events where:

- Activation of stakeholders
- Informing the stakeholder (e.g. technology, plans for local pilot runs, strategy)
- Initiate networking between stakeholders and project partners
- Definition of expectations, technical realities and socio-economic situation in round table discussion
- Discussion of the results on behalf of their impact on investment activities
- Visit to Pilot B for better understanding and getting a touch on the technology

1.5.4 Curriculum

The curriculum in this report shall give an idea of what kind of content should be trained in the different phases and what skills and competencies should be acquired for a successful operation of pilot B and a proper education responsible people. It is based on the experiences of the operation periods in Lithuania, Estonia and Sweden and the first training, done in Germany just before the start in Lithuania.

This curriculum shall give a guideline of what should be considered and trained, when the plant is located at a specific place with the objectives

- to train the operator as a preparation for the operation of a full scale plant
- to train the operator to do a training on the pilot plant by himself
- to train academic personnel to do testing with different substrates

	Content	Duration
Training in Laboratory	Basic analytic skills, interpretation of results, theory on operation of digestion plants, field visit of a full scale plant	5 days
Training on the job	Start, operation and stabilization of a technical anaerobic digestion process.	3 months
Training of Trainer (ToT)	Didactic basis for the training on the plant	3 weeks

[3]

1.5.5 Target group

The content of the curriculum is designed for university graduates with a degree in engineering or other technical faculties. Depending on the experiences in analytic laboratories handling with waste, digestate or comparable substrate the first training phase might be not necessary.

1.5.6 Training Phase in laboratory

The first training was realized at the laboratories of the Ostfalia Universities and for a proper training that should be the start of the training.

Duration

5 days

Content

Get to know the starting and operating of the batch of anaerobic digestion, including the different phases of the AD process and the parameters to be analysed.
To learn how to do continuous tests for evaluation of different substrates for biogas production, determination of different parameters for process and substrate evaluation (DM, oDM, NH4-N, VOA/TOA, pH, CH4-, CO2-, H2S-concentrations, concentrations of organic acids)

Excursions to a full-scale dry digestion plant and to Pilot B.

Objectives

The objectives of that training are, to acquire following skills and competencies:

- to take trials and to do the necessary test
- to interpret the analysed parameters in the way to recognize that the process is stable
- to acquire the necessary knowledge for operation of an anaerobic dry digestion plant with focus on the starting phase

[3]

2. Summary of the single operating periods

The following chapter will summarize the three operating periods (in Lithuania, Estonia and Sweden). It's meant to point out country specific differences and challenges. It will also show the technical advantages of plug flow dry digestion technology regarding its ability to deal with a large bandwidth of different waste materials. Beside the practical tests, financial and economic studies have been performed. On the basis of the biogas yields from practical testing, different scenarios for full scale investment have been studied. A third part of every operating period was the development of a proper strategy of communication for best inclusion of the stakeholders.

2.1 Lithuania

Lithuania was the first partner country to run experimental tests with Pilot B. The plant had been set up on a small farm. As main substrate cow manure from the farm itself has been used with later admixture of distillery waste, food waste from local kindergartens and algae from the Curonian Spit.

Figure 7: Pilot B setup in Lithuania. Picture taken on stakeholder event 24th June 2013.

The main focus has been set to the training and the information of the local people. Resulting from this, local staff has been able to do the onsite training for the next operating period in Estonia and as well later in Sweden.

The interest in the technology, especially from local farmers, was high. A good example for this was the participation of 35 local stakeholders on the second stakeholder event in June 2013 (see Figure 7).

2.1.1 Summary of technical operation

As the intention was to use local available waste streams, the resulting mixture to feed the fermenter contained:

- Cow manure from the farm
- Distillery leftovers from a local bioethanol factory
- Food waste from schools and kindergartens in Klaipeda
- Algae collected at the beaches of the Curonian spit

(See Figure 8)

Figure 8: Substrates used in Lithuania. Cow manure (top left), Distillery leftovers (top middle), Algae (top right), Food waste (Original, mashed, sanitized) (from bottom left to right).

The feeding amounts can be seen in Figure 9. The food waste had been pre-treated in a pressure cooker for sanitation purposes.

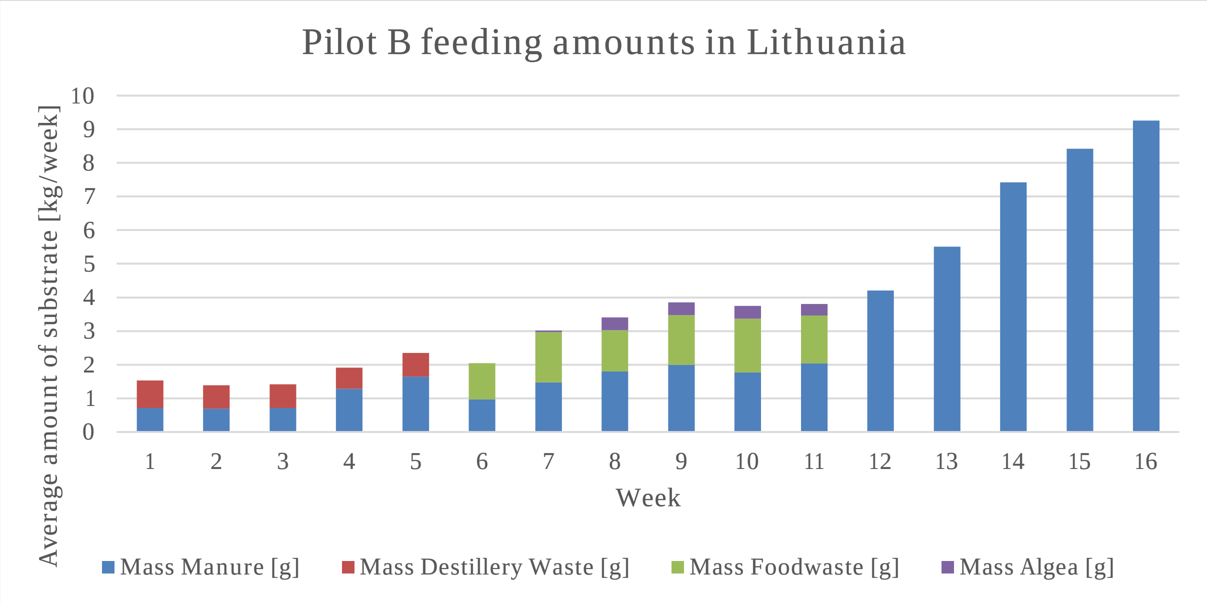

Figure 9: Overview on Pilot B feeding amounts during operating period in Lithuania.

As there have been parallel tests run at the Ostfalia laboratory, the individual biogas yields for each substrate have been known. From these data and the feeding amounts, it has been possible to assess the fermentation process in the pilot plant. As can be seen in Figure 10, the plant showed a very good production performance. Only in the first weeks of operation the production rate was far higher than estimated. This was a result of initial overfeeding followed by a non-feeding-time to allow the system to recover.

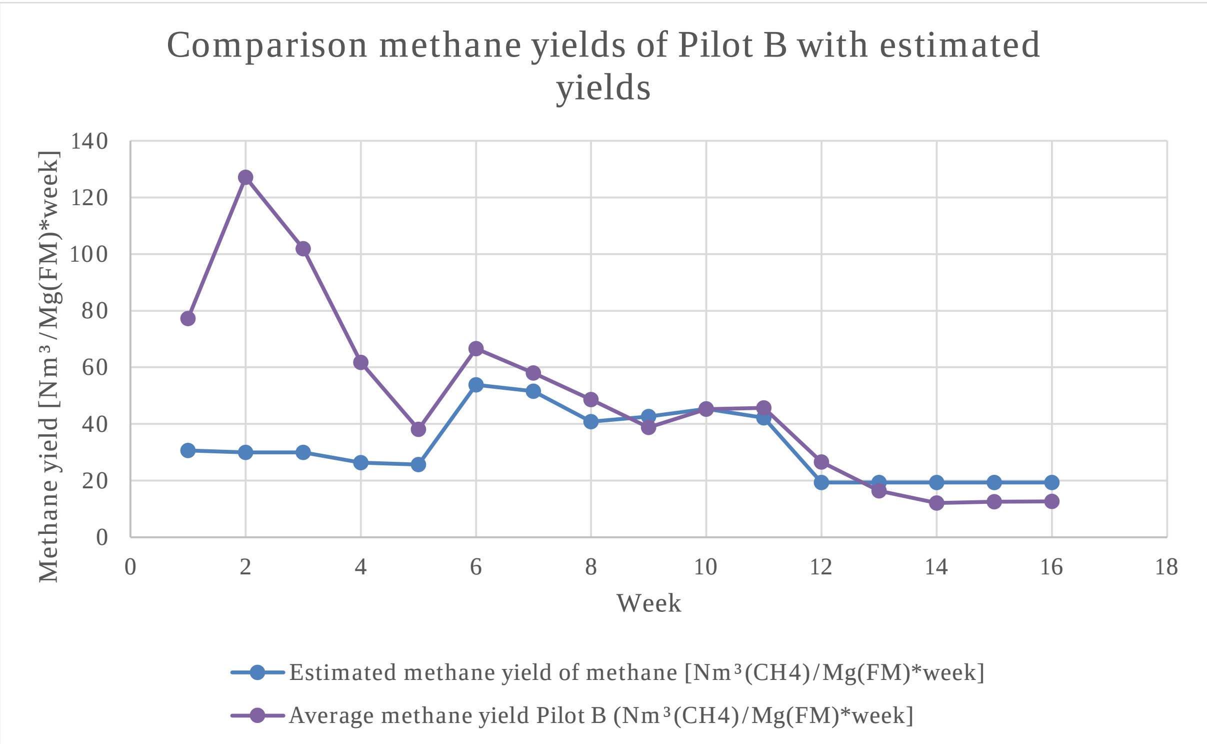

Figure 10: Comparison of methane yields of Pilot B in Lithuania in comparison with estimated yields calculated from batch tests performed in Ostfalia laboratory.

Table 6 gives an overview of the Lithuanian operating period in numbers.

Table 6: Overall data for Pilot B operating period in Lithuania

Overall mass manure	519.09 kg
Overall mass distillery waste	35.62 kg
Overall mass food waste	82.68 kg
Overall mass algae	15.39 kg
Overall mass	652.78 kg
Overall volume of produced biogas	38.62 Nm^3
Overall volume of methane	21.85 Nm^3
Resulting average methane concentration	56.6 %
Fermenter temperature	42°C (mesophilic)
Overall electricity consumption	2,183.8 kWh

2.1.2 Summary of financial implementation report

This chapter delivers the first economical calculations for the investment in full scale biogas technology. The numbers are based on German biogas plant data, on Lithuanian data and also on some assumptions. The summary chapters on financial implementation will show the development of the calculation method during the project. A summary will be given in Chapter 3.2)

The calculation method used is the discounted cash flow (DCF). The discounted cash flow constitutes a calculation method to estimate the attractiveness of an investment opportunity. The discounted cash flow method is often used in investment finance, calculating the future cash flows of present values. The purpose of a DCF analysis is to estimate the benefit which will arise from an investment and to adjust for the time value of money. [18]

For Lithuania, a theoretical scenario has exemplarily been calculated. The basic numbers for this calculation can be found in Table 7.

Table 7: Technical data as a basis for cash flow calculation for Lithuanian Scenario (52% manure + 38% food waste + 10% algae; 500 kW CHP unit).

Estimated methane production manure	19.34 Nm^3Mg^{-1} (FM)
Estimated methane production food waste	85.23 Nm^3Mg^{-1} (FM)
Estimated methane production algae	30.90 Nm^3Mg^{-1} (FM)
Average methane content	57%
Organic dry matter content manure	10.66%
Organic dry matter content distillery waste	11.52%
Organic dry matter content algae (dried)	27.53%
Resulting energy demand	10,683 MWh
Resulting methane volume	1,071,507 m^3a^{-1}
Annual feeding amounts	12,237 Mg manure + 8,942 Mg food waste + 2,353 Mg algae
Remaining residues after fermentation	21,390 Mg
Resulting fermenter volume	3637 m^3

The calculated cost are shown in Table 8.

Table 8: Specific costs for the exemplary Lithuanian calculation.

	500 kW Scenario: (cow manure + food waste + algae)
Investment costs (total)[1]	2,700,000 €[3]
Required working time	2000 hours/year
Personnel costs[2]	~1,000 €/month[4]
theoretical revenues (electricity; without deduction of own requirements)[2]	648,240 €/year (0.148€/kWh)
Operating costs (total)	150,672 €/year[6]
Substrate costs[2]	none
Maintenance and repair (CHP) [1]	56,940 €/year
Maintenance (total, up to 6%)	135,000 €/year (6%)

[1] based on German data base

[2]Lit. Lithuanian specific data

[3]Assumption: 20% higher investment costs because of necessary pre-treatment

[4]based on assumption: average monthly salary 646.43 € + social security contributions

[5]based on SODRA, but no more indications concerning working hours and hourly rate

[6]based on figure 42

Table 8 is partly based on the following specific data:

- Investment costs for 500 kW-biogas plants: 4,500 €/kWel
- 1 €=~3.4528 Lt
- 6% of investments – for maintenance

The calculation results from Table 8 result in the cumulative discounted cash flow shown in Figure 11.

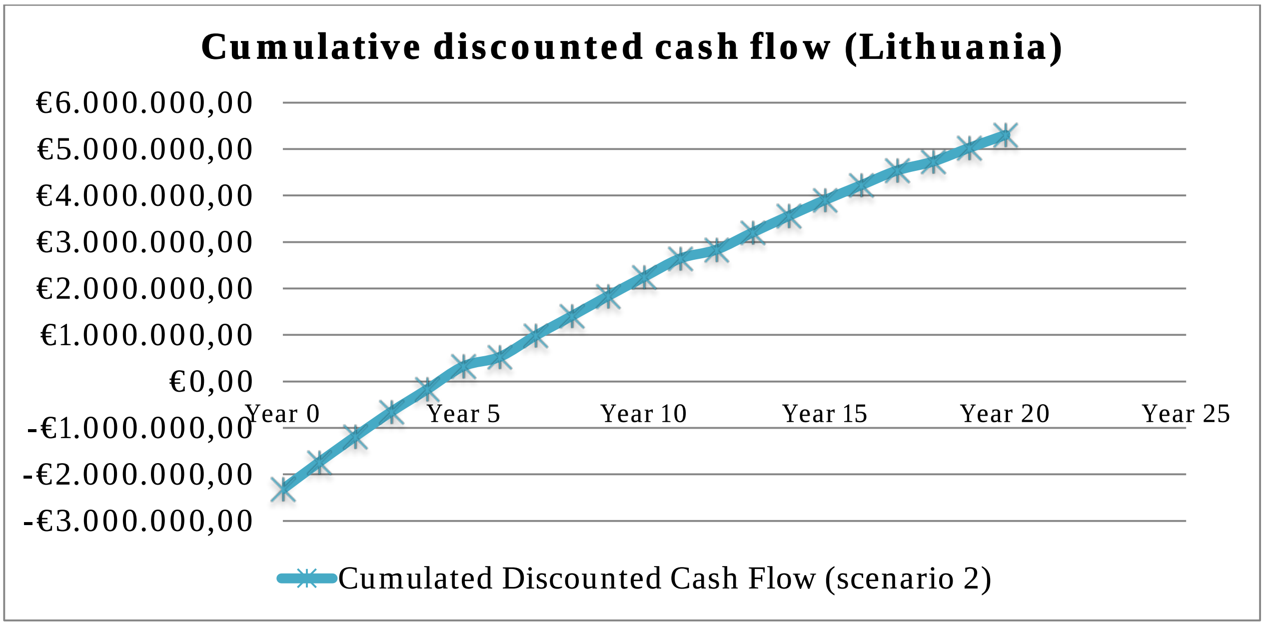

Figure 11: Cumulative discounted cash flow for biogas plant with plug flow fermenter (Lithuanian numbers).

2.1.3 Summary of communication strategy

Marketing strategy

The stay of pilot B was the first step of an introduction strategy. The known technology of anaerobic digestion shall be shown as a useful and economically interesting possibility to treat different kinds of bio waste. In this niche several experts in Western Lithuania may decide and they are capable to foster or to hinder the implementation of this technology. So the marketing strategy was, to reach these important stakeholders and to convince them, that the anaerobic digestion is a good answer to the question: How shall we treat the organic waste so that the EU Landfill directive can be fulfilled until 2016?

The communication strategy enabled the WP-Team and the project partners from WP2 to come into contact with the important stakeholders and deliver data and information to them that was noted. The discussions showed, that there is an opportunity for anaerobic digestion to be implemented in the region and local aspects could be included into the investment memo.

At the end a broad support from the stakeholder couldn´t be reached so that a strategy for whole Western Lithuania could not be introduced. But the Town of Švėkšna showed interest so that on a next step the calculation of an anaerobic digestion plant for that municipality gives the opportunity to show that the technology is feasible, which could lead to the planning and construction of a plant and/or to a further process of discussion of that technology among the experts.

Change process

The anaerobic digestion technology in Lithuania is known as a technology which is used to treat sewage sludge, manure from big pig farms or for the treatment of digestate. The use of that technology for the treatment of manure from small farms and bio waste is new. Obstacles are reservations like "is it economically feasible?" or prejudices like "it stinks and it is dangerous". These obstacles are in the direct environment as well as in the group of stakeholder.

The stay of pilot B sensitised the neighbours of the site where it stayed that the technology can be handled and that its perils are not uncommon high. They could see, that a trained operator can run the plant in a secure way and that the educts are in a good quality. The experts could see, that the anaerobic digester can treat different kinds of substrates and that the process is stable.

Missing is a "change leader", that is an organisation, a person, an institution that fosters the technology independently from resistance from outside and within his peer group. There is a well-trained engineer and a research institute that are convinced that anaerobic digestion is a good and suitable technology. They have the possibility to support a coming change leader which could arise from the results of the approach to calculate a digestion plant for Švėkšna.

Education strategy

The results showed clearly, that for the operators the theoretical training in the laboratory has to be accompanied by practical units on the plant. The training of Vygintas Daukšys was so successful, that at the end he could work as a trainer for the future operator. Especially the aspects of trouble shooting and interventions in crisis are an essential part of the training. If the curriculum would include some didactical and methodical aspects the training of the operator could be designed as a ToT (Training of Trainer).

The training of the local environment is very useful in that way, to involve the neighbours actively into the communication process. So their concerns can be addressed to invent solutions. Originally this aspect wasn´t considered in the curriculum, so that the further project shall show, if it should become a part of the education strategy.
[3]

For detailed information about the Lithuanian operating period please see Output Report O4.3 (“Midterm Output Report – Pilot B operation in Lithuania”). This report can be downloaded on www.abowe.eu .

2.2 Estonia

As second country to run local tests with the pilot plant, the setup in Estonia was on a big local milk producing agricultural farm. As there is a huge amount of cow manure produced, the main issue was to seek advantages in the energetically utilization of this waste stream. As there are already existing biogas plants in Estonia and as well in the region around Kaarli Farm OÜ, the biogas process is well known in Estonia.
One big issue is the way how to treat the digestate. At the moment the digestate is not commonly accepted as a good quality fertilizer. This is a problem for plant operators, as they have problems to get rid of their digestate [19]
In addition tests to check on fertilizer qualities before and after fermentation have been handed over to a national laboratory (Estonian Agricultural Research Centre (Põllumajandusuuringute Keskuse).

Figure 12: Pilot B setup in Estonia. Picture taken on stakeholder event 17th December 2013.

2.2.1 Summary of technical operation

The only substrate during the Estonian testing period was cow manure gathered from the slurry pit as seen in Figure 13. Due to rain water flowing into this pit the dry matter content of the material varied a lot. The operation of the pilot plant with manure was unproblematic as it was constructed for much tougher material. Only the sealing of the stirring shafts showed some minor leakage that stopped after short period of time.

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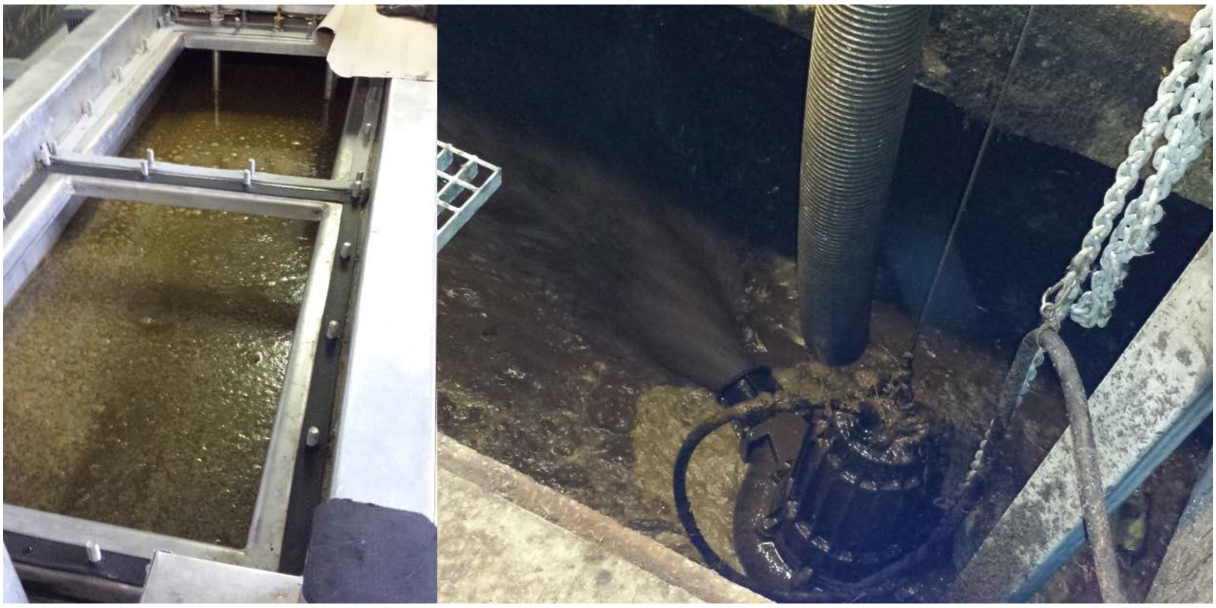

Figure 13: Cow manure was the single substrate during the Estonian operating period. Pilot plant (left), slurry pit (right).

As the consistency of the manure changed on a daily basis, the overall biogas yield was pretty low. Compared to manure used in Lithuania 7.5 Nm³/Mg (FM) less CH_4 production (see Table 20 later in the report in Chapter 3.1). The influence of the fluctuating DM/oDM content is mirrored in the data shown in Figure 14, as there is no stable correlation between gas production and feeding amount visible.

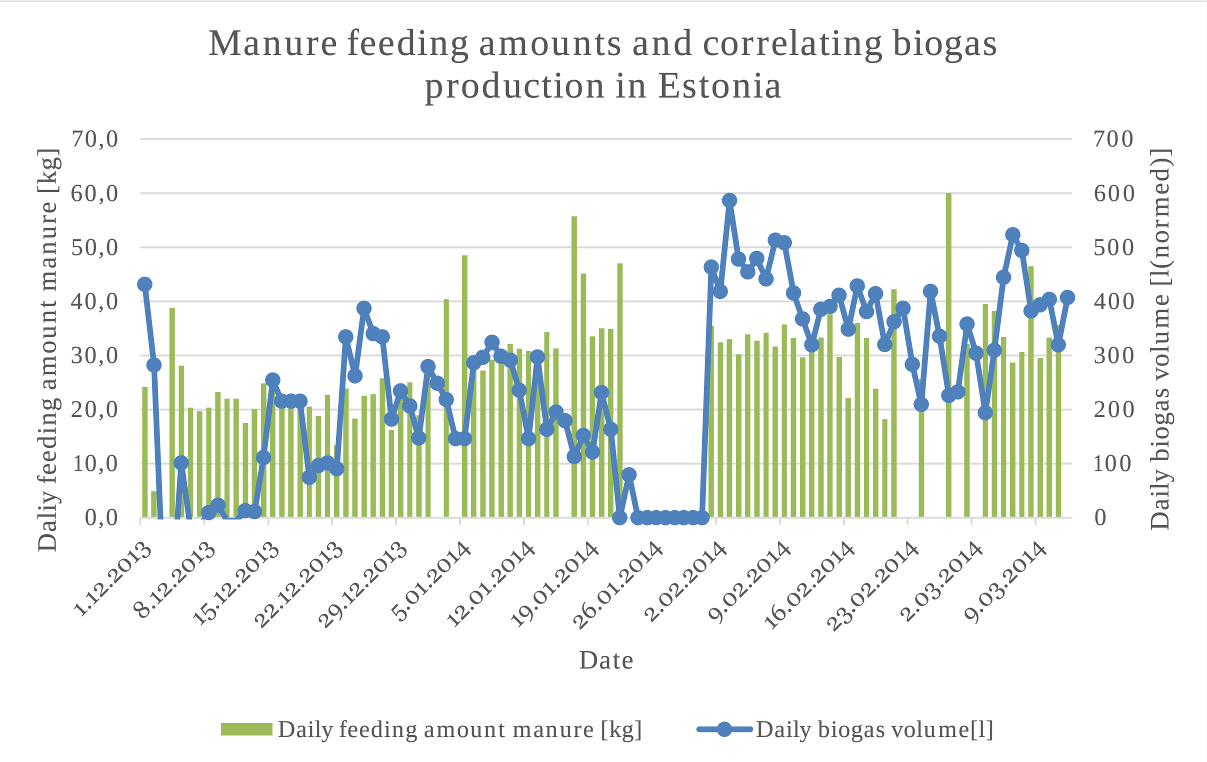

Figure 14: Manure feeding amounts and correlating biogas production in Estonia.

Some numbers of the Estonian operating period are given in Table 9.

Table 9: Overall data for Pilot B operating period in Estonia

Overall mass manure	2606 kg
Overall mass silage	4,3 kg
Overall volume of produced biogas	54,103 Nm^3
Overall volume of methane	30,78 Nm^3
Resulting average methane concentration	56,9 %
Resulting methane volume per Mg fresh substrate	11.8 Nm^3/Mg(FM)
Fermenter temperature	55°C
Overall electricity consumption	3778 kWh
Total plant runtime	approx. 21 weeks

2.2.2 Summary of financial implementation report

As described in earlier the discounted cash flow constitutes a calculation method to estimate the attractiveness of an investment opportunity. The discounted cash flow method is often used in investment finance calculating the future cash flows present values. [18]

Based on the data in Table 10 and the conditions given on the Estonian farm cumulative discounted cash flows of a biogas plant with different scenarios were calculated. The results are shown in Figure 15.

Table 10: Database for the calculation of the model biogas plant. [17]

size of the plant: 96 kW, 830 m³ digester, 211,773.00 m³ CH4/a (378,166.00 m³ biogas/a (56% CH4, 19 Nm³/ton; based on Lithuanian analytical results), 10.950 m³/a manure, 842.009 kWhel/a (40% el. efficiency rate); 40 % th. efficiency rate			
	specific costs	**costs for the plant**	literature source/database
total investment costs[1]	7,000€/kW (averaging)	700,000.00 €	[8]
Digester[2]	1,500€/kW, 200€/m³ (estimation)	160,000.00 €	[9]
CHP unit incl. control and torch[3]	1,750€/kW	175,000.00 €	[8]
personnel costs[4]	0.25 work day	3,000.00€/year	[7, 9 and own calculations]
maintenance and repair[5]	0.02*378166	7,563.00 €	0.02€/m³biogas [own calculations]
service contracts[6]	0.03*378166	11,345.00 €	0.03€/m³biogas [own calculations]
purchased services and goods[7]	0.01*378166	3,782.00 €	0.01€/m³biogas [own calculations]
purchased electricity[8]	0.096€/kWh (6% increment rate)	6,099.06 €	7.5% electricity demand (plant)=63531,9kWh
			[own calculations]
replacement of CHP unit every 6 years			
revenues:			
Electricity[9]	0.093€/kWh (6 % increment rate)	78,306.88 €	electricity price [10];
Digestate[10]	3.58€/t (2 % increment rate)		[own calculation]; (16€ per t of manure (20%TS)) [7]
Heat	0.04 €/kWh (6% increment rate)		620561 kWhth (heat demand of the plant (26.3 %) excluded)
first revenues in year 1, after construction in year 0			

[1] database [9], average value (75kW-, 150 kW-plant); value reduced, because plant operated only with manure has less investment costs than average [6]
[2] estimation based on costs for digester (plants of different sizes) [12]
[3] average value [6]
[4] required working time based on [12]; average wage level [20]
[5,6,7] calculated operating number, based on data of different German biogas plants
[8] price based on yearly electricity demand and costs for the farm
[9] feed-in tariff (subsidy included) [20]
[10] calculation based on the price for manure 16€/t (20% FM) [20]; here 6,7 % FM (see detailed calculation in Table 10: Database for the calculation of the model biogas plant)

Description of different models in Figure 15

1. Model with sale of electricity and digestate: complete sale of the produced electricity and digestate, purchase of for the biogas plant needed electricity (0.096 €/kWh), farm demand of electricity not considered.
2. Model with sale of electricity, heat and digestate: complete sale of the produced electricity, recovery of heat demand of the biogas plant and sale of residual heat, sale of digestate, purchase of for the biogas plant needed electricity (farm electricity demand not considered).
3. Model with sale of electricity, without sale of digestate: complete sale of the produced electricity, no sale of digestate and purchase of for the biogas plant needed electricity (0.096 €/kWh), farm electricity demand not considered.
4. Model with covering of farm and plant energy demand, sale of remaining electricity and digestate: covering of electricity demand of biogas plant and farm, sale of remaining electricity, sale of digestate; conservation of electricity of the farm included as revenue (excise duty calculated as expenses).

ˇ

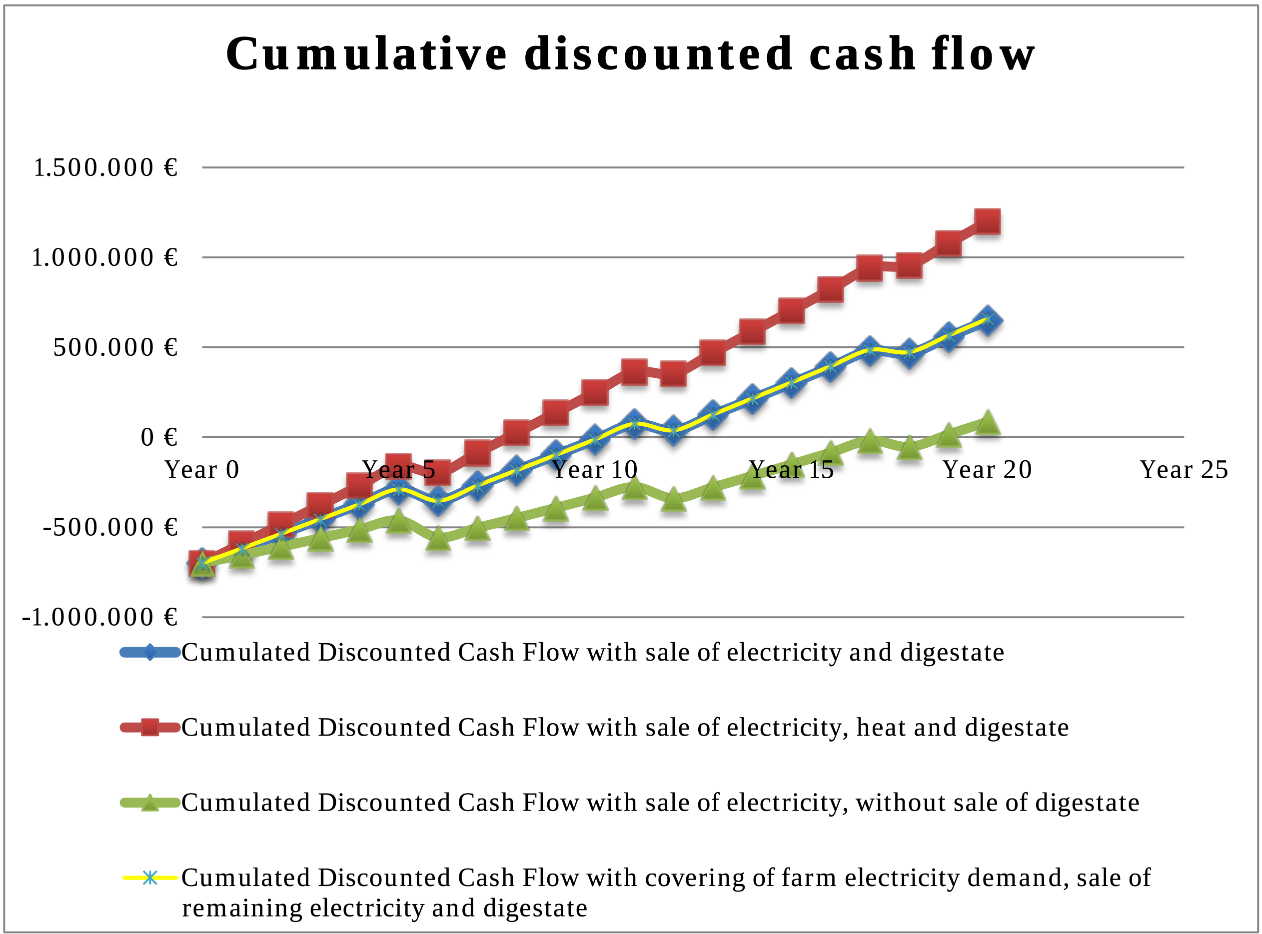

Figure 15: Cumulative discounted cash flows for different scenarios.

In the calculation of the above described model biogas plants a discount rate of 5 % was set.

The increment rate regarding the sale of electricity was set to 6 %, because that is an average value based on the development of the electricity prices. The increment rate regarding the sale of digestate was set to 2%, according to general price rises (also of mineral fertilizers).

Also the increment rates of the single operating costs are set to 2 % because of the general average values concerning the price rises.

The calculation with covering of the farm and plant electricity demand with own produced energy excise duty was considered (4.47 Euros per MWh).

Additionally two models were calculated which show the differences caused by the size of the plant. They are shown in Figure 16.

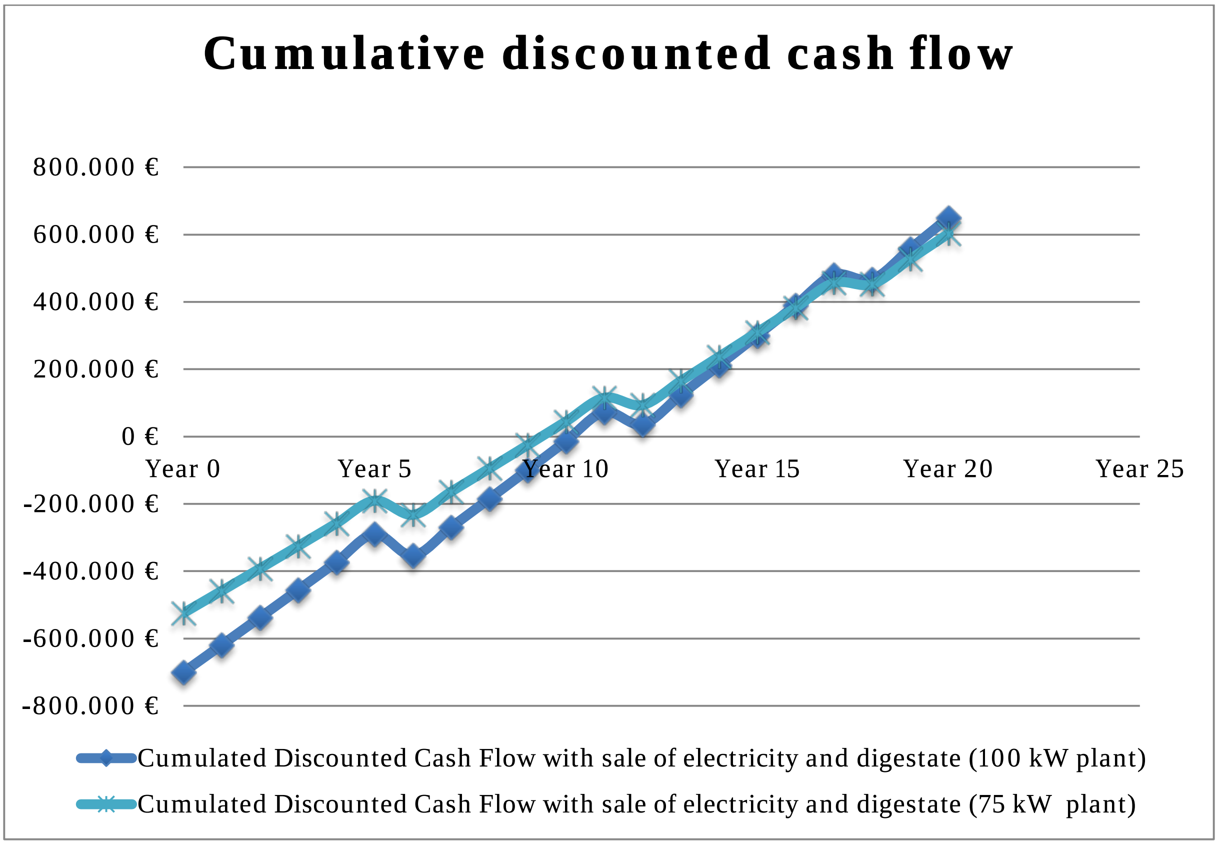

Figure 16: Cumulative discounted cash of exemplary manure based biogas plant (75 kW) in comparison to the manure based plant (100 kW).

As expected the two curves in Figure 16 show comparable courses. The 75 kW-plant reaches the zero line one year earlier, because of the lower investment costs, but after reaching this point the curves approach and latest in year 16 the 100 kW-plant curve proceeds above the curve of the 75 kW-plant. [17]

2.2.3 Summary of communication strategy

The Estonian partners are strongly rooted in their local and national environment that included a solid way of communication with the relevant actors. For that reason a strategy for communication needn´t to be invented. It was more effective to accompany the local partners and support them when demanded. This led to an adapted concept of the operation and an efficient way of communication that created sincere attention and concrete requests regarding investment possibilities.

Additionally the experience in Estonia shows, that the training programme for the operator had been optimized in a way, that local staff after the introduction into the pilot B operation at Kaarli Farm immediately was able to operate the plant in a secure and stable way. [17]

For detailed information about the Estonian operating period please see Output Report O4.4 ("Midterm Output Report – Pilot B operation in Estonia"). This report can be downloaded on www.abowe.eu .

2.3 Sweden

The Swedish testing period differs from the ones in Lithuania and Estonia. As there have been mostly pure biological waste streams being examined in the pilot plant. In Sweden municipal solid waste (MSW) has been utilized.

Figure 17: Pilot B setup in Sweden. Composition area of local waste treatment facility VAFAB Miljö AB.

2.3.1 Summary of technical operation

The pilot plant has been fed with pre-sorted MSW (see Figure 18). The feeding rate has been raised during time of operation, which can be seen in Figure 19. The final loading rate was approx. 4.0 kg (VS)/m³*day which meant approx. 10.5 kg (FM)/ day. Due to a lack of staff and time it was not possible to have the complete fermenter volume exchanged for at least one time.

Figure 18: Different batches of MSW shredded and sieved to a size ≤40 mm. This has been the substrate used in Sweden.

As the feeding rate was increased during the approx. 90 days of testing, the biogas volume being produced did not show the same significant increase. This could be reasoned by the inhomogeneous MSW. The waste was stored in a more or less open container. Rain water was able to wash out material and the waste was rotting for some days before being fed. Figure 19 shows the development of the gas production rate and the related feeding amounts.

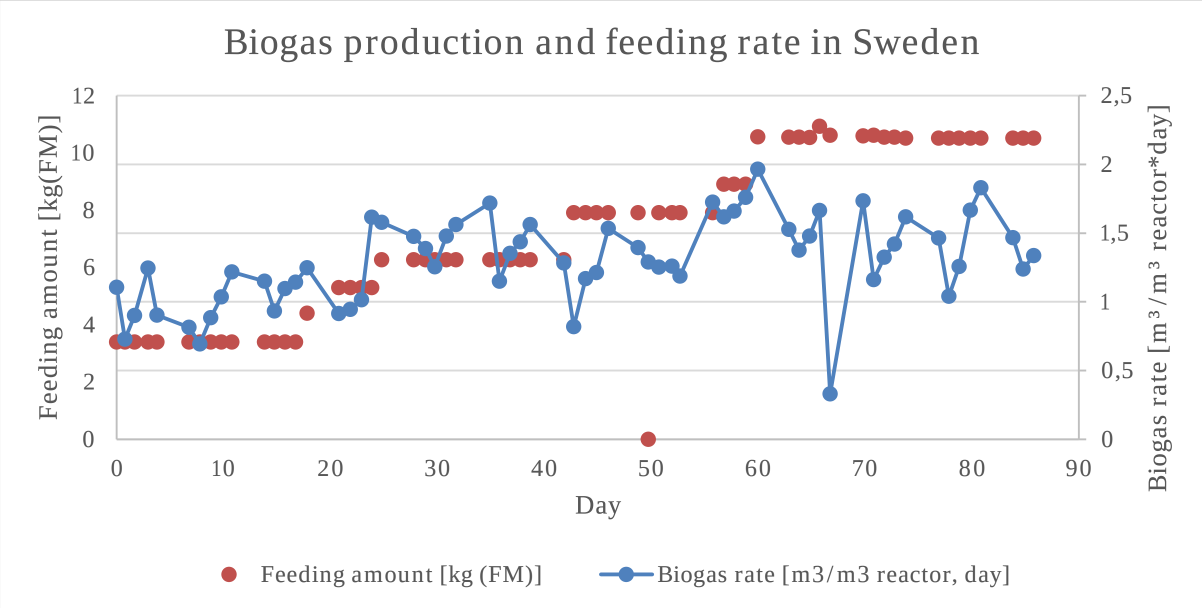

Figure 19: Biogas production and feeding rate during Swedish operating period.

Figure 20 shows the development of the different gas concentrations. As the measuring device for H_2S was broken, these values are missing. The average methane concentration in the biogas was 58.29%, resulting in an average methane yield per ton of fresh MSW of 75.7 m^3 / Mg (FM).

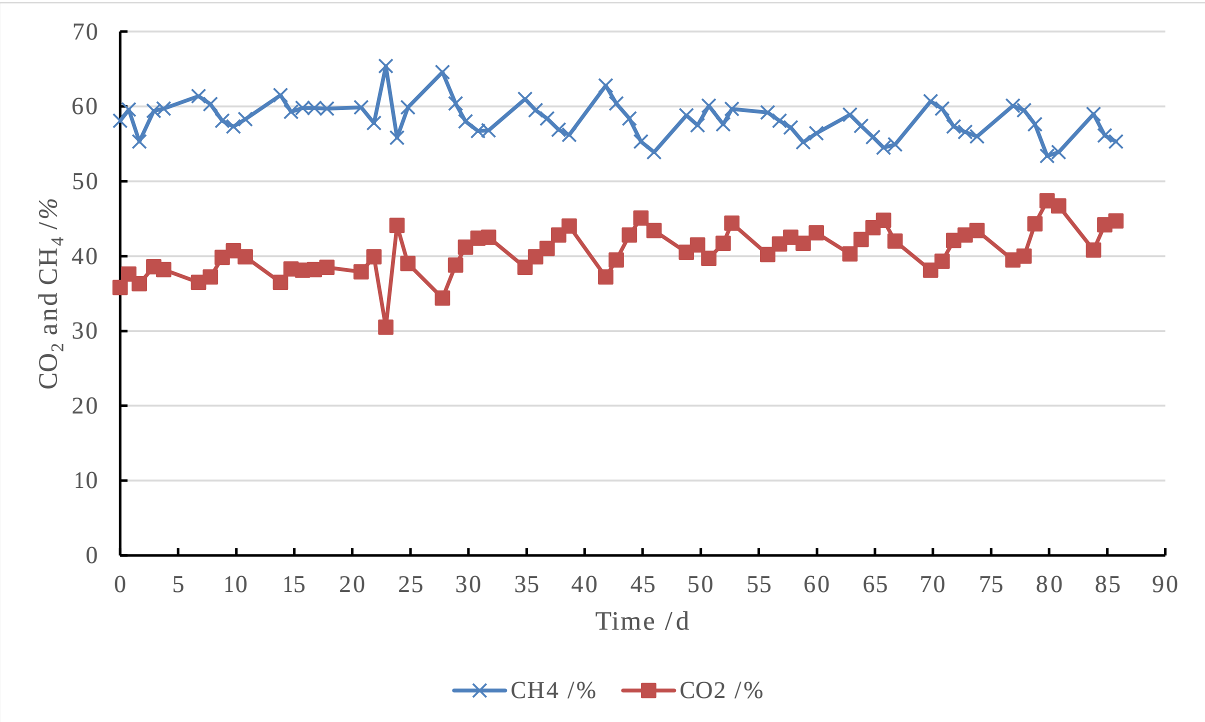

Figure 20: Biogas yields of the MSW during the Swedish operating period.

The concentrations of selected heavy metals is displayed in the following tables 11, 12 and figures 21, 22. All of the selected heavy metals show the trend of accumulating during the time of operation. For more significance a long term study is necessary. [4]

Table 11: Concentrations of selected heavy metals (Cu, Cr, Ni, Zn, and Mn) in the digestate.

Date	Cu (mg/kg TS)	Cr (mg/kg TS)	Ni (mg/kg TS)	Zn (mg/kg TS)	Mn (mg/kg TS)
28.04.2014	47	19	11	110	-
22.05.2014	79	63	33	260	310
04.06.2014	89	58	25	310	320
17.06.2014	93	94	36	300	290
01.07.2014	100	130	63	300	270
15.07.2014	90	57	28	320	270
23.07.2014	93	110	40	320	270

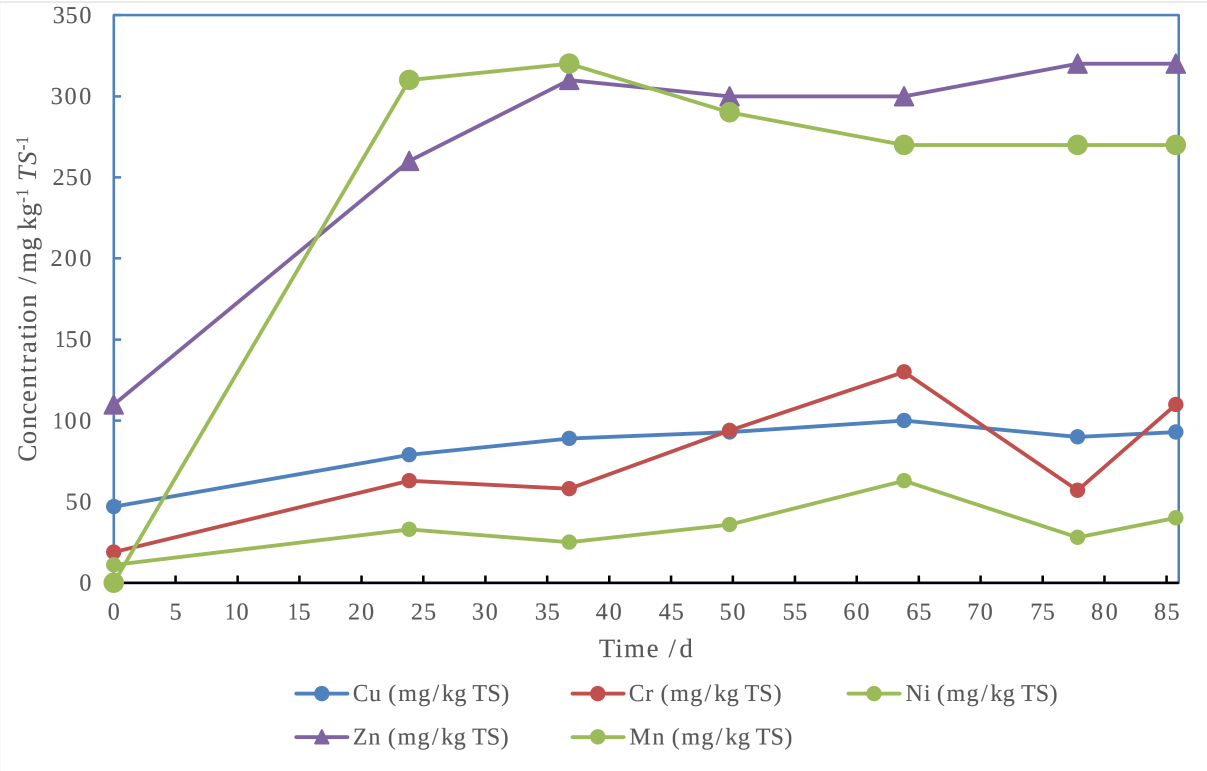

Figure 21: Concentrations of selected heavy metals (Cu, Cr, Ni, Zn, and Mn) in the digestate.

Table 12: Concentrations of selected heavy metals (Pb, V, As, Mo, Co, Hg) in the digestate.

Date	Pb (mg/kg TS)	V (mg/kg TS)	As (mg/kg TS)	Mo (mg/kg TS)	Co (mg/kg TS)	Hg (mg/kg TS)
28.04.2014	5.9	-		3.1	4.8	0.033
22.05.2014	16	11	1.8	-	5.6	0.026
04.06.2014	21	13	2.2	-	6.4	0.036
17.06.2014	26	14	2.2	-	5.4	0.039
01.07.2014	27	14	2.2	-	4.5	0.037
15.07.2014	28	8.4	1.8	-	3.6	0.043
23.07.2014	49	10	2	-	3.5	0.035

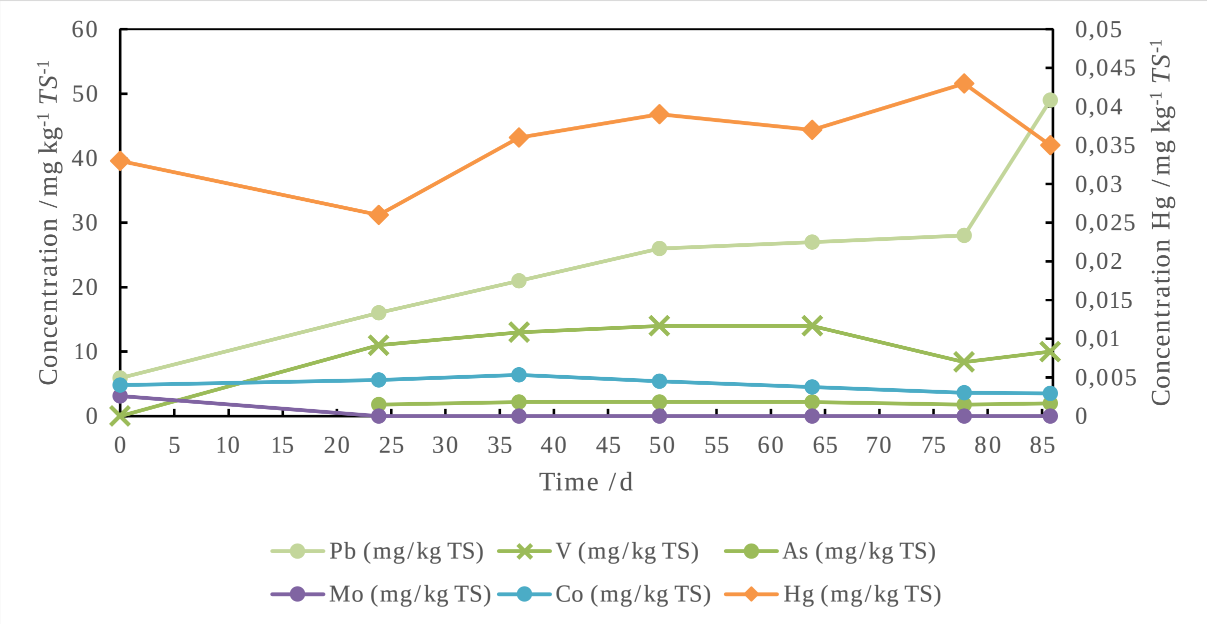

Figure 22: Concentrations of selected heavy metals (Pb, V, As, Mo, Co, Hg) in the digestate.

The heavy metal concentration also plays an important role for the economic calculations for a plant treating such a waste. As there might be costly actions required to dispose contaminated digestate, this topic should be observed carefully.

One main problem when working with MSW as a substrate is the handling of the digestate. Due to a huge bandwidth of harmful substances in the MSW that can accumulate in the digestate the disposal or follow up utilization as a fertilizer can become problematic.

The disturbing materials such as stones, metal parts and plastics can accumulate in the system and also cause heavy damages to the fermenter equipment, see figure 23.

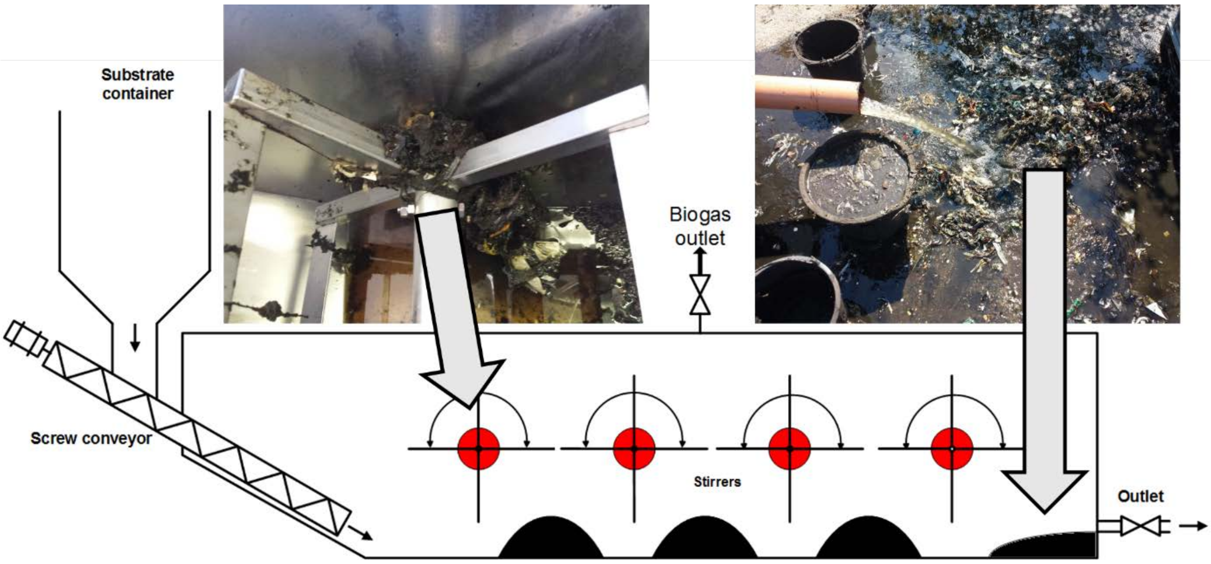

Figure 23: Plastics wrapped around the stirrer shaft/blades (left, red). Glas, stones and metal parts sediments (right, black).

Resulting from these difficulties, the amount of digestate that needs to be treated should be kept to a minimum. To avoid technical process problems, a reduction of disturbing material, as mentioned above, should be taken into account.

As an alternative solution, a different dry fermentation strategy was taken into account; this additional strategy will be described in the following chapter 2.3.2.

2.3.2 Additional pilot scale tests with garage fermentation system

Besides the practical testing with Pilot B (see output report O.4.2., O.4.3.and O.4.4. for more details of previous tests in Lithuania and Estonia), a pilot scale garage fermentation system has been used during the Swedish operating period.
The use of this system has been taken into account, because it allows to use unsorted MSW. Unlike the other systems used, the substrate was utilized as it was provided by the VafabMiljö team (see Figure 18). In full scale this could save a pre-treatment of the waste, which would make the process much cheaper. On the other hand, the biogas yield would be lower, due to a higher share of indigestible material.
Table 13 gives an overview on general data of the garage digestion system used in the Ostfalia laboratory.

Table 13: general fermenter data

component	**data**
inner volume	approx. 480 litres
substrate volume	approx. 125 litres
percolation liquid volume	approx.125 litres
data logging	temperature (substrate, percolation liquid, gas), gas composition, gas amount

In this garage fermentation system the substrate is stored in a removable tub. The percolation liquid is being sprinkled over the substrate. A further component are two packed columns. These should support a permanent colonization of microorganisms which are required for the process. This also should ensure a faster restart of a new batch. Furthermore the fermenter is equipped with different possibilities to record process relevant data. Figure 24 shows a flow sheet of the garage fermenter.

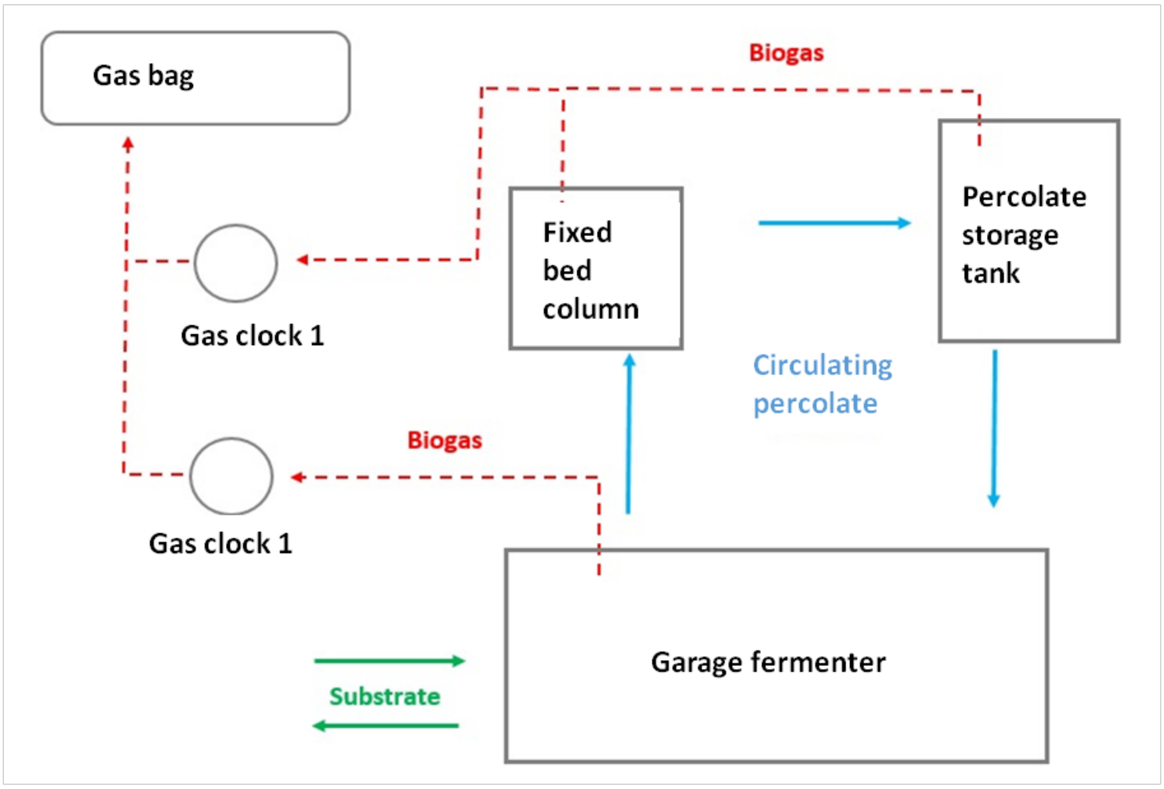

Figure 24: Flow sheet of the experimental lab size garage fermentation system.

Figure 25 shows the exterior of the garage fermenter. It is equipped with a hot water heating system. The percolation liquid is being sprinkled on the substrate. It is then drained at the end of the fermenter. It flows via two fixed bed columns to a percolation liquid storage tank.

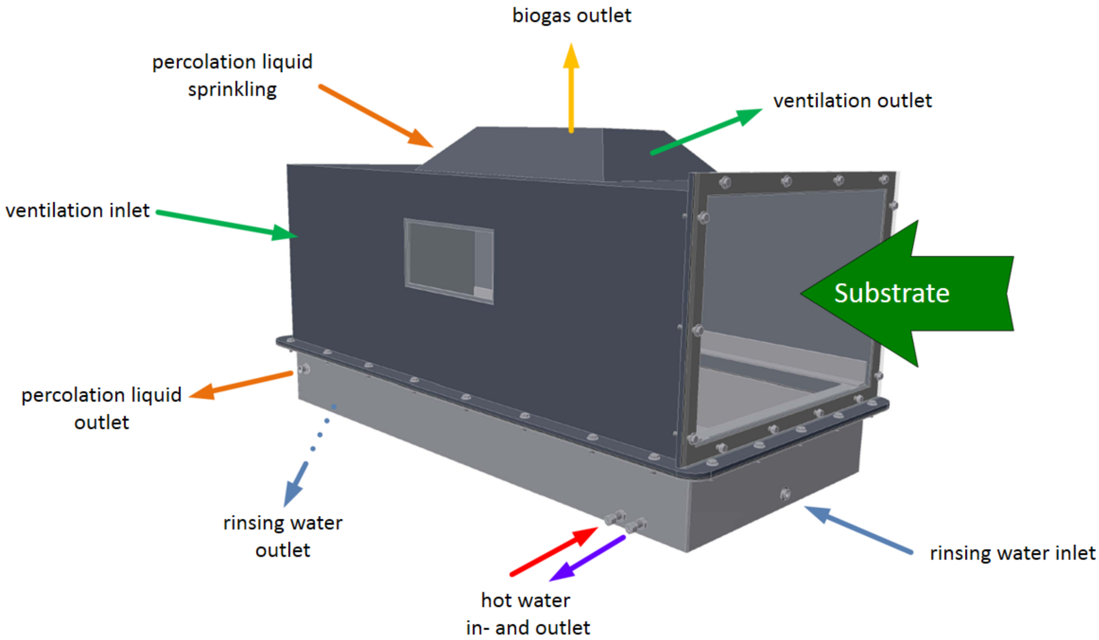

Figure 25: Exterior view of the garage fermenter and some of its components.

In Figure 26 a see-through view of the garage fermenter is displayed. The removable container has got holes in the bottom, so that the percolation liquid can drain. The temperature sensors for gaseous- and solid phase can also be seen.

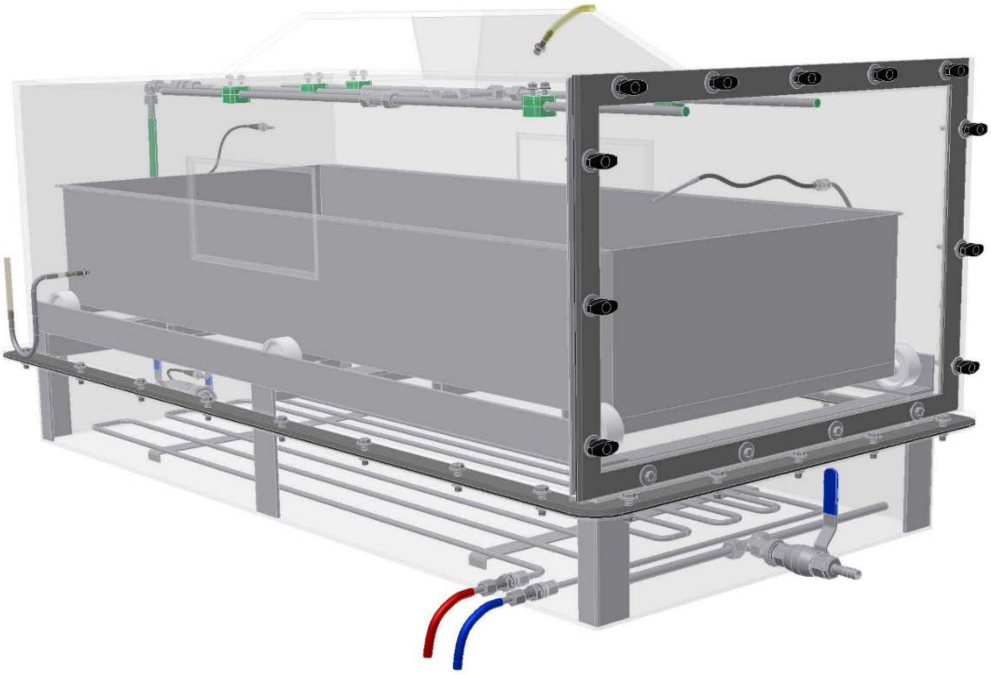

Figure 26: See-through view of the experimental garage fermenter with its components.

In Germany the mentioned garage fermentation system has been tested with the same MSW samples used in Sweden. Figure 27 shows the biogas volume that has been produced and as well the corresponding methane concentration during an exemplary batch run.

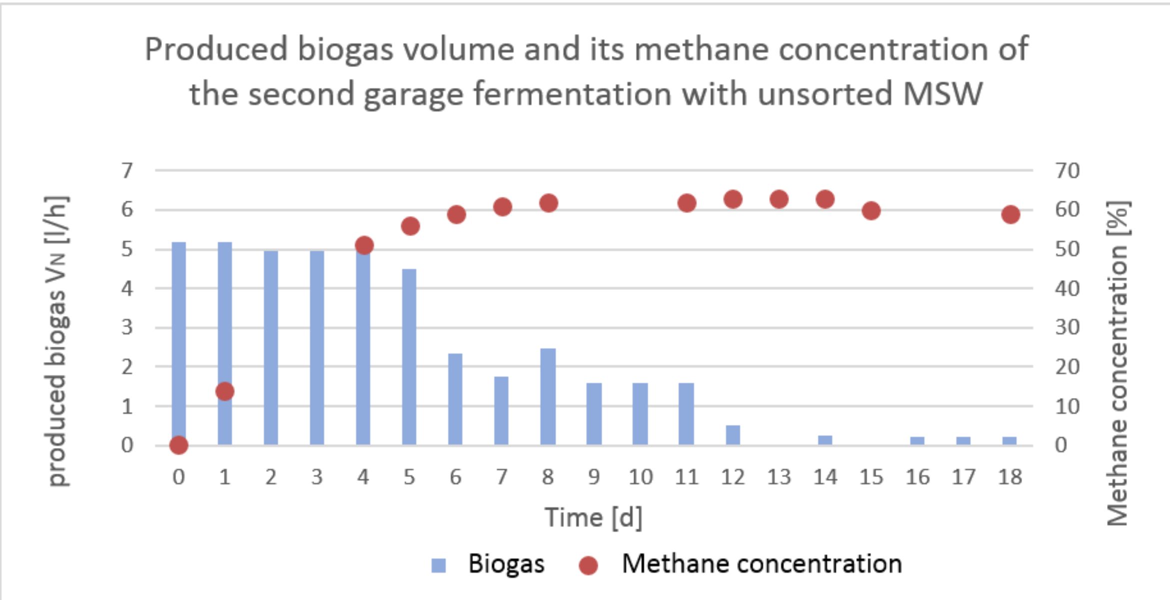

Figure 27: Produced biogas volume and its methane concentration of a garage fermentation with unsorted MSW.

The results allow the conclusion, that dry fermentation following the garage principle is suitable for the Swedish MSW utilization scenario.

2.3.3 Comparison of different fermentation strategies

In the following, the results from the different fermentation methods mentioned above shall be compared. Table 14 gives an overview of the methane yields from each of the different fermentation methods.

Table 14: Results of each fermenter for overall comparison

Fermenter Type	Substrate pre-treatment	Average CH4/fresh mass (Nm³/Mg FM)
Average from thermo- and mesophilic batch tests	Sorted, sanitation at 70ºC for 1 h	68.48
Mesophilic Wet Digester	Sorted, sanitation at 70ºC for 1 h	70.96
Thermophilic Dry Garage Fermenter	Unsorted, no pre-sanitation	53.95
Thermophilic Plug Flow Fermenter	Sorted, no pre-sanitation	75.78

Results show, that plug flow dry digestion offers the best methane yield per ton of fresh MSW (75.78 Nm^3/Mg FM). The results of the mesophilic wet digestion are close to the one from dry digestion, but it must be said that the possible organic loading rate of these fermenters is much smaller. So that in comparison the overall production rate of a full scale plant of comparable dimension would be much lower.
Garage fermentation has the lowest production rate (53.95 Nm^3/Mg FM). But it must be taken into account, that the waste used in the garage fermentation has not been pre-sorted. So at least up to 25% of the input material would not have been biodegradable. [4]

Overall data show a good biogas production by MSW. Compared to literature data, biowaste produces approx. 110 Nm^3 (biogas)/Mg (FM)[1] with a methane content of 60%. This data matches quite well with the data gained in the practical tests with MSW. With consideration of the share of undegradable matter in the MSW the results are very promising.

[1] Graf, Bajhor; Biogas – Erzeugung, Aufbereitung, Einspeisung; Oldenbourg Industrieverlag GmbH, 2011; page 285

The biological treatment of MSW leads to high contents of heavy metals so that in Germany in accordance to the Waste Disposal Directive and the EU Landfill directive the disposal of the digestate from MSW fermenters is obligatory. The biological treatment of MSW is not seen as recycling but as a pre-treatment before disposal and thus in its aims equivalent to those of waste incineration:

- minimisation of volume and mass
- inertization of the waste (minimization of the organic fraction)
- concentration of pollutants

The digestate of the treated waste is stabilized (mostly aerobically composted) to reduce smell emissions and improve the deposit ability and afterwards landfilled. [4]

Table 15 gives a final overview of the Swedish testing period in numbers.

Table 15: Overall data for Pilot B operating period in Sweden

Operating time	86 days
Overall mass MSW	446.97 kg
Overall volume of produced biogas	44.88 Nm^3
Overall volume of methane	26.09 Nm^3
Resulting average methane concentration	58.3 %
Fermenter temperature	55°C (thermophilic)
Overall electricity consumption	1,787.9 kWh

2.3.4 Summary of financial implementation report

For the calculations the following assumptions were made:

- Gate fees incineration (costs): 30 €/t (estimation)
- Gate fees MSW (revenues): 60 €/t (estimation)
- Tariff for electricity: 0.06379 €/kWh + VAT
- Tariff for district heating: 0.041 €/kWh + VAT
- Tariff for gas as vehicle fuel: 1.16 €/Nm^3

The tariffs are based on the references mentioned in Table 16.

Table 16: data for biogas plant with plug flow fermenter and garage fermenter (based on own lab tests/pilot tests and calculations).

	Plug flow fermenter	Garage fermenter
Substrate: MSW for plug flow fermenter: 56 % CH4-amount, 75 Nm^3/ton MSW for garage fermenter: 56 % CH4-amount, 54 Nm^3/ton[1]	30,000 tons (untreated) resulting 24,000 tons MSW (pretreated), 75 Nm^3/ton FM	30,000 tons MSW, 54 Nm^3/ton FM
Resulting theoretical biogas yield (eff. 90%, estimation)[2]	2,892,857 m3 Biogas/a	2,603,571 m3 Biogas/a
Resulting theoretical methane yield (gas loss max. 2%)	1,619,676 m3 Ch4/a	1,428,840 m3 Ch4/a
Digestate	19,977 tons	26,379 tons

[1] result from lab size fermenter and Pilot B operation

[2] in case of batch test results

Various cost items required for proper calculations are given in Table 17

Table 17: cost items for the cash flow calculation of a biogas plant with a plug flow fermenter (start values).

Cost item	**Costs in €**	
	Plug flow	**garage**
Investment costs (total)[2]	4,121,330[6]	2,853,229
- Upgrading facility[2]	1,545,499	1,069,961
Operational expenses		
- Maintenance and repair[3]	43,392	39,054
- Maintenance, repair and operation of upgrading facility[4]	216,964	182,250
- Other purchased services and goods (analytics, fresh water, waste water, others)[3]	28,928 28,928	26,035 26,035
- Other administrative costs[3]	86,818	77,755
- Heat production[3]	77,039	23,188
- Electricity[3]	49,517	71,870
- Personnel costs (operational labor, feeding and administrative labor)[5]	20,606	14,266
- Insurance	86,785	78,107
- Other operational costs (service contracts)[3]	62,930	63,377
- Transport costs (digestate)[1]	599,322	791,390
- Digestate disposal[1]		
Revenues		
- Gas sale[1]	1,878,824	1,657,454
- Income from substrates[1]	1,800,000,00	1,800,000

[1]based on estimation, at the time of start-up

[2]based on [6]

[3]based on Table 18

[4]based on [21]

[5]based on [11]

[6]incl. 30% addition

Table 18: determined key values for cash-flow calculation (valid for plug flow fermenter system).

Key value	**Number**		**Method for determination**	**Source/ database**
investment costs	€/Nm^3*h (table 2)		average values of different agricultural biogas plants	literature [FNR]
personnel costs	€/month		based on Figure 6	literature [FNR]
working time per day and month	8 hours/day 160 days/month			general assumption
additional personnel costs (administrative)			depending on the size of the plant;	
service contracts	0.03(€/Nm^3)*biogas yield (Nm^3/a)		calculation of average values	data of different German biogas plants
maintenance and repair[2]	0.015 (€/Nm^3)* biogas yield (Nm^3/a)		calculation of average values	data of different German biogas plants
purchased services and goods	0.01 (€/Nm^3)*biogas yield (Nm^3/a)		calculation of average values	data of different German biogas plants
other administrative costs	0.01 (€/Nm^3)*biogas yield (Nm^3/a)		calculation of average values	data of different German biogas plants
Operating costs for upgrading	0.07 €/m^3		based on Figure 5	
operating hours of the plant	8760 h		general assumption	
Insurance	0.5% (of investment)		general assumption	
discount rate	10%		general estimation	
increment rate (revenues; biogas)	6%		general estimation	
increment rate (digestate sale)	2%		general estimation	
increment rate (operational costs)	2%		general estimation	
	plug flow	**garage**		
additional personnel costs (feeding)	2 min/ton[4]	4 min/ton		literature [FNR]
own electricity demand	15 % of produced energy[3]	5 % of produced energy[3]	calculation of average values	data of different German biogas plants

own heat demand	26.3% of produced heat[1]	26.3 % of produced heat[1]	calculation of average values	data of different German biogas plants

[1]based on [14]; based on the theoretical value in case of electricity production with CHP-unit
[2]0.025 (€/Nm³)*biogas yield (Nm³/a) for biogas plants with CHP-unit
[3]estimation; based on the theoretical value in case of electricity production with CHP-unit
[4]based on [14]

Results of the cash flow calculations

Based on the data which are listed in Table 16, Table 17 and Table 18 theoretical cumulative discounted cash flow calculations were made (see figure Figure 28).

- Plug flow fermenter system

Basing on a theoretical amount of 30,000 tons municipal solid waste (MSW), what means after a pre-sorting an amount of 24,000 tons would be available for the anaerobic digestion (based on the results of the pilot B-testing), a plug flow fermenter system has been calculated. The results are related to the assumption that all of the produced biogas will be upgraded and sold as vehicle fuel. The filling stations and other necessary peripheral equipment is already available and therefore no additional investment costs occur.

- Garage fermenter system

Because there will probably be no complex pretreatment of the substrate necessary, the calculation based on the whole amount of 30,000 tons MSW for the anaerobic digestion. Apart from that the same assumptions as for the plug flow fermenter are valid.

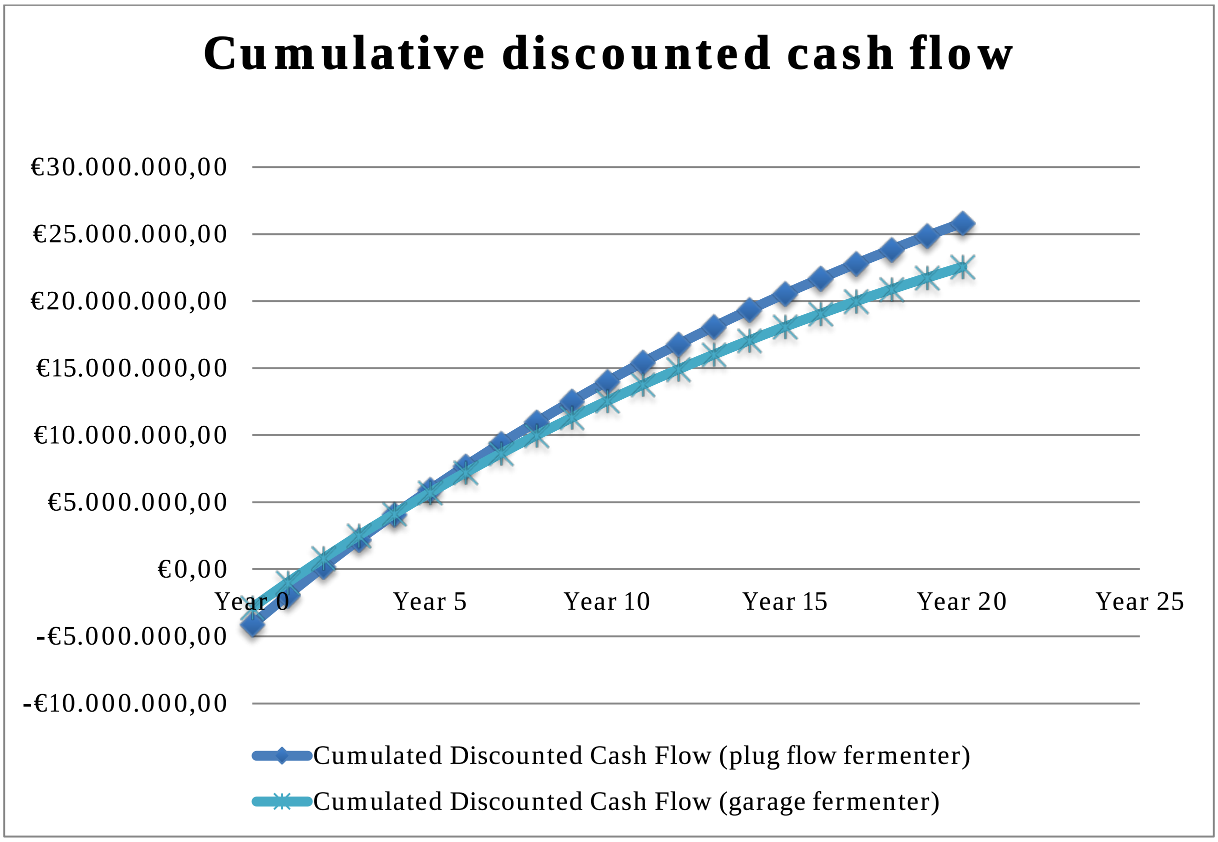

Figure 28: cumulative discounted cash flow for biogas plant with plug flow fermenter and garage fermenter.

Both calculated and presented cumulative cash flows are based on assumptions. These assumptions have to be considered critically and have to be updated continuously.
Therefore the calculations can only give rough tenements concerning the development of the cash flows.

However the theoretical and exemplary calculations show the profitability of the possible scenarios. The garage fermenter as well as the plug flow fermenter system would reach the “break-even point” within the first two years (provided the external periphery and also management and administration is largely available) under the assumed conditions. Here the earned profit out the sale of the biogas is one of the most influential factors.

For the development and planning of a real biogas plant offers of manufacturers for sure have to be obtained.
The upper described scenarios and cash flow models can only be seen as rough considerations.

For a detailed calculations the data have to be adapted to the real conditions and requirements. [4]

2.3.5 Summary of communication strategy

The last stop of the dry digestion pilot, pilot B, within the ABOWE project was in Västerås, Sweden. It was situated on the property of an already existing wet digestion biogas plant. The local partners, the Mälardalen University as well as naturally VAFAB (the operator of the biogas plant), have comprehensive expertise with regard to the digestion technology. The objective of the operation period of pilot B had clearly been specified before its arrival in Sweden and VAFAB had strongly been involved.

Pilot B operation should prove that the dry digestion technology is capable to treat biowaste and municipal solid waste in a stable way and show that the methane yields are viable with the overall aim to gain trust in dry digestion technology.

VAFAB got the order to triple the biogas production within the next three to four years and has been searching for possibilities to increase the productivity of the already existing plant and to find a technology that is proved and stable to treat waste streams that have not been treated by now. The operation of the existing wet digestion plant is expensive, a fact that leads to the search of alternative technologies.

Not only the Västerås municipality but also others in Sweden have decided to use much more biogas in public transport so that stakeholders from other regions are interested in the results of the pilot B operation as well.

If the results of the project ABOWE show that this consideration is technically feasible the possibility that a dry digestion biogas plant will be built using this fraction of the MSW as substrate is much more likely.

While carrying out the technical tests, key stakeholders in the waste sector in Västmanland County have been informed about the project and results from the piloting.
The 13th of June key stakeholders were invited to a half-day workshop where the dry digester was discussed and demonstrated. The purpose of the meeting was to inform stakeholders and to discuss how dry digestion can be a solution to current and future waste management needs in the region and beyond.

In preparation for this event the project team contacted stakeholders and conducted an informal interview to learn more about challenges and opportunities in the waste sector in Västmanland County. Posters presenting the project and results so far were also prepared

Pilot B operation should prove that the dry digestion technology is capable to treat biowaste and municipal solid waste in a stable way and show that the methane yields are viable with the overall aim to regain trust in dry digestion technology. The known technology of dry digestion shall be shown as a useful and economically interesting possibility to treat different kinds of waste. The experts in Västerås may decide to foster or to hinder the implementation of this technology. So the marketing strategy was, to reach these important stakeholders and to convince them, that the dry digestion is a good answer to the question: How can we better exploit the energetic potential that is captured in the biogenic part of our waste?

The communication strategy enabled the WP4-Team and the project partners from WP2 to come into contact with the important stakeholders and deliver data and information to them that was noted. The discussions showed, that the question is not if digestion plants are built but what kind of technology is going to be chosen. [4]

To meet the needs of the main stakeholders, the garage fermentation was presented as an additional technology that can anaerobically treat municipal solid waste. The results of the tests in the pilot garage fermenter in the laboratory of Ostfalia delivered helpful additional data for the decision process of the stakeholders.

The decision on the investment and the corresponding technology has not been made until such time as this report has been written.

For detailed information about the Swedish operating period please see Output Report O4.5 ("Midterm Output Report – Pilot B operation in Sweden"). This report can be downloaded on www.abowe.eu .

3. Comparison of operating periods

This chapter will compare the three different operating periods regarding technical, economic and communication issues. It shall reflect the continuous development during the project. As mentioned before e.g. the adaption and enhancement of the economics calculations (see Chapter 1.4.4) was a continuous process.

First of all Table 19 gives an overview of the different testing countries of Pilot B.

Table 19: General overview of the different places

	Lithuania	**Estonia**	**Sweden**
location	small farm	large farm	waste treatment plant
substrates	manure, biowaste, algae	manure	municipal solid waste
state of digestion technology	uncommon technology	common technology	common technology
legislative framework	no pressure	no pressure	high pressure
focus, pilot B as	place of learning	place of research	place for testing
perspectives	further studies	unknown	further research
probability of investment	middle	middle	high
local partners	University of Klaipeda	ERKAS - Estonian regional and local development agency	Mälardalen University

The data given in the table above gives a good impression on the partially huge differences of challenges in every country. The learning process will be summarized in Chapter 3.4 .

3.1 Comparison of technical operation

As the individual challenges, regarding the specific substrates in this case, are not directly comparable, Figure 29 just gives an overview of the country specific biogas/methane production and the related feeding amounts.

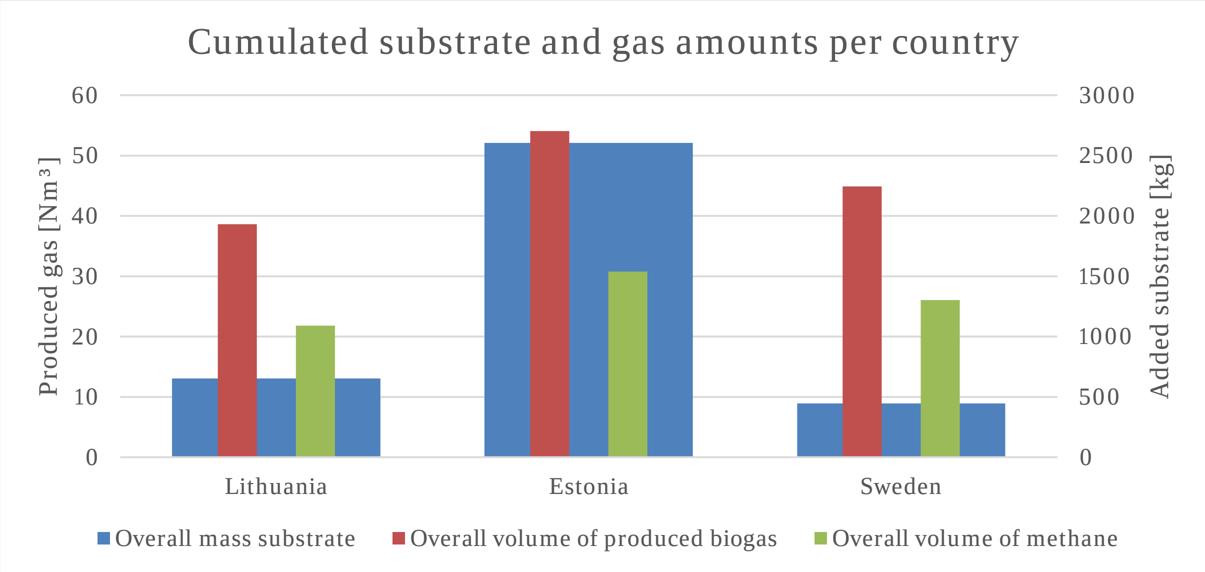

Figure 29: Comparison of overall feeding amounts and the total biogas/methane production in each country.

Looking back, the technical part of the project has not been the most challenging part of the project work. This can be explained by the sophisticated technical equipment. In spite of the fact that there have been minor technical difficulties, the technology of plug flow dry digestion proofed itself as reliable. The difficulties derived from natural wear.

Looking at the two most different substrates, cow manure and MSW, the flexibility of the technology becomes even clearer. Table 20 gives a final overview of the country specific biogas productivity regarding the individual substrates.

Table 20: Biogas productivity and Substrate specifics.

	Lithuania	**Estonia**	**Sweden**
Methane production (manure) [Nm³/Mg(FM)]	19.34	11.8	-
Methane production (food waste) [Nm³/Mg(FM)]	85.23	-	-
Methane production (algae) [Nm³/Mg(FM)]	30.9	-	-
Methane production (MSW) [Nm³/Mg(FM)]	-	-	58.37
Average methane content (Vol. %)	56.6	56.9	58.1
Overall biogas production (Nm³)	38.62	54.103	44.88
Overall methane production (Nm³)	21.85	30.78	26.09

3.2 Comparison of financial analysis

The "Financial implementation report" was meant to give an impression on the various aspects thinking about implementation of biogas technology. As mentioned before, a continuous development has been going on over the whole project runtime.

Therefore extensive enquiries were made about cost factors in a general way as well as in reference to existing biogas plants (especially using examples of German biogas plants). Because it is really difficult to get economic data from biogas plant operators these cost factors are mostly described in terms of specific costs or exemplary calculations on the basis of data from plant construction firms.
Basically prices for investment and operating are varying between the countries. Concerning investment it has to be proved which plant components are economically reasonable to be manufactured in the country where the biogas plant will be built and which plant component is better to import.
Concerning operating costs there are many variations possible. Especially the personnel costs are one of the most differing cost factors from country to country.

Substrates which can be an central cost factors are of important interest. Because waste was considered to be used as input material, the costs which arise are absolutely different to the costs which arise using renewable raw materials (possibly there is even an income by gate fees).

A detailed calculation and estimation of cash flows is only possible by defining concrete system models. On the basis of these data (based on commercial offers) a detailed calculation of cash flows and with that the investigation of the economy of a planned biogas plant is possible. With data which has been collected in the following of the project and in other partner regions a general outlook and estimation for the financial implementation on a common basis has been developed.

Comparing the summarized cash flow calculations in the Chapters 2.1.2 , 2.2.2 and 2.3.4 the evolution of calculation detail is obvious.
Beginning from Lithuanian calculations with basic assumptions and theoretical scenarios the factors that have been implemented in later calculations constantly rose.
Resulting in the very complex Swedish calculations.
Mayor exemplary factors that have been added during the project are:

- Integration of costs for transport of substrate and digestate
- Possible disposal costs for digestate
- Adaption of country specific labour costs
- Covering of own energy demands
- Costs for biogas upgrading
- Costs for wheel loader fuel
- And much more...

A concrete case arose from the first milestone of the project ABOWE which is the Scenario for the village Švėkšna which will be described as a proof of concept later in this report (see Chapter 4.).

3.3 Comparison of communication

During its journey the strategy of communication had the national and regional stakeholders in focus. To inform them and to ensure their engagement with the aim to foster investment into dry digestion technology a strategy of communication had been implemented

3.3.1 Identified stakeholders

The situation in Sweden and Estonia was quite different to that in Lithuania due to the fact, that in both countries (Sweden and Estonia) the technology of anaerobic digestion has been established in the field of biogas treatment of cow manure in Estonia and in the field of waste to energy technologies in Sweden. Nevertheless the group of stakeholders in all three countries was comparable.

About 20 to 30 institutions were identified in each countries to be involved in the process. Some state institutions were invited to a dialogue in all three countries (see Table 21), mostly with responsibility on a regional / local level and / or active in the fields of energy supply, waste treatment. Country specific was the selection of companies and private institutions, depending of the structure of the market in the fields of energy supply and waste treatment.

Table 21: Identified stakeholders.

In all countries	**in some countries**
State institutions	
• Energy and/or Environmental Protection Agencies • Municipalities • Institutions on regional level • Agricultural institutions • Waste management • Energy supply	• Ministries (Environment, Energy, Economy) • Waste water treatment • Research institutions • Health care
Companies and private institutions	
The identified companies and private institutions varied broadly for the different countries.	• Waste management • Energy supply • Planning engineers for dry digestion • Farmers • Financing institutions • Environmental services • Biogas companies

The results of a questionnaire that was answered by stakeholders in Lithuania showed, that the participants of the process are curious to see whether the new technology will be established in their country. Further results were, that the participants named, that the biggest potential of biogas technology in Lithuania is connected to agriculture. Further on the main obstacle regarding the development expected in the lack of financial sources and the doubt, that that technology can be run with profit. Also the lack of knowledge had been seen as a very important challenge on the way of implementing that technology in Lithuania.

3.3.2 Local Partners

The local partners in Lithuania and Sweden were research institutes, whereas the local partner in Estonia was a regional development agency. Each partner had two persons who were responsible contact points for the project partner and the stakeholders in the countries (see Table 22)

Table 22: Local partners.

	Lithuania	Estonia	Sweden
local partners	University of Klaipeda	ERKAS - Estonian regional and local development agency	Mälardalen University
persons in charge	Olga Anne and Vygintas Daukšys	Jaan Lõõnik and Priit Freyenthal	Eva Thorin and Patrik Klintenberg

From the communicative point of view the local partners were designing the way of communication in the country, they brought in their personal and professional network as the source of all activities regarding presenting and representing the project. Mostly the differentiation between the both main actors was, that one was more responsible on the institutional strategically level whereas the other was more active on a local and operative level.

3.3.3 Events

At least three events took place in each country the first as a kick-off, to inform and to check the expectations of stakeholders and doing planning for the stay, the second as an intermediate meeting for information of stakeholder and partners and the last to present the results and the investment memo. Regarding time frame and participants see Table 23.

Table 23: List of Events.

	Lithuania	Estonia	Sweden
Kick-off	**Stakeholder meeting**	**Workshop**	**Preparatory meeting**
	Within the first month after arrival of pilot B	Within the first month after arrival pilot B	Three months before the arrival of pilot B
	about 30 participants 15 Lithuanian stakeholders	about 20 participants, mostly Estonian stakeholders	about 20 participants with the main stakeholder
Intermediate events	**Stakeholder visit**	**Stakeholder event**	**Stakeholder event**
	about three months after arrival of pilot B	about three months after arrival of pilot B	about two months after arrival of pilot B
	about 30 Lithuanian visitors	about 20 participants,	about 20 participants,
Final events	**Stakeholder event**	**Investor event**	**Investor event**
	in the last month of the stay of pilot B in Lithuania	in the last month of the stay of pilot B in Estonia	after the stay of pilot B in Sweden
	about 15 participants, 5 national stakeholders	about 15 participants, mostly Estonian stakeholders	

Kick-off

The kick-off events had a highly activating and interactive character, opened by high representatives from the universities or from ministries, followed by informative presentations giving an introduction into dry digestion, the pilot B concept and the targets of the investment memo. The second part dominated by discussions within the national stakeholders and with the international experts. In Lithuania methodology for this part was a world café, in Estonia and Sweden round table discussions were used. The results of these discussions built the basis for the scenarios that were considered in the countries.

Intermediate events

A visit of pilot B was part of all programmes of the intermediate events that were used to inform the stakeholders about the midterm results and to show them how the plant is functioning, where and what the obstacles had been, which solutions had been found and what the next steps were supposed to be. Lively discussions took place and some ideas could be created, to optimize the results of the stay of the pilot plant. Focus of these events was on the technical aspects and on the availability and utilisation of substrates, whereas economical topics were considered more deeply in the final events.

Final events

At the end of the stay the technical results were presented and the conclusions of the scenarios shown. An outlook on the investment memo took place and the stakeholders were asked to comment the results and to give some feedback. The stakeholder discussed what impacts the results were going to have on their activities and where investment could be viable.

Factors for a successful communication

- Identification of relevant stakeholders
- A problem in the country/region that could be solved by dry digestion
- A strong local partner and its network
- The definition of appropriate scenarios
- Regular contact to the stakeholders (monthly at least bi-monthly)
- The offer of the pilot plant as a place of learning for both, the researcher and the stakeholder

3.4 Conclusions from the learning process

As no concrete investment effort derived from the Lithuanian operating period the question for the reasons arose. It turned out, that addressing a lot of individual stakeholders was not a proper way of action in Lithuania. Most of the stakeholders have been farmers with big interest in the technology, thus they have not been able to invest in biogas technology alone. Furthermore no will of cooperation between multiple farmers by forming of joint ventures for investing was noticeable.

So the first approach in Lithuania failed.

As the plant was almost on its' way to Estonia the nearby community of Švėkšna showed interest in the technology after all. The authorities of the community took the chance to visit the plant before it was transported.

By addressing a community the chances for full scale invest rose. Deriving from this a new approach was made, fostered in cooperation of Lithuanian and German project partners. As a result a more concrete scenario has been created. This scenario shall develop a possible biogas plant in the town of Švėkšna to substitute the energy supply of a local hospital by energy from local waste.

This scenario is described in more detail in Chapter 4. of this report, acting as a proof of concept for the strategy described in Chapter 1.2 . If the local authorities show interest in full scale implementation deriving from the concept, further cooperation will be driven forward.

The stakeholder feedback in Estonia was quite reserved. The impression was a little ambivalent, as the interest in the technology seemed to be present but the stakeholders did not come up with personal approaches.

As an outcome the proof of digestate as a high quality fertilizer in comparison to ordinary manure could be an outcome. The future cooperation may result in new project activities which could lead to an investment.

The Swedish period already lead to possible continuation of cooperation. The community of Örebro showed big interest in additional substrate investigations. As they have high amounts of grass available on the one hand side and a big demand for biogas on the other.

If the outcomes of this project lead to a better decision-making when it comes to the full scale investments, continuation of scientific-/consulting activities is likely to happen.

4. Proof of concept – Implementation scenario of a full scale biogas plant for the community of Švėkšna, Lithuania

This chapter will describe a case study for biogas implementation following the approach explained in Chapter 1.2 .

The case studies deals with the implementation of a small size biogas town for the town of Švėkšna in Lithuania. The basis for the technical calculations are given by the amount of substrate that is locally available. The financial modelling is based on the utilization of heat and electrical power by a local hospital.

4.1 Introduction

The concept shown in Figure 30 shall be deepened in this chapter.

A biogas plant will be planned according to this scheme. It should partly substitute electricity and heat demand from fossil fuels of a hospital in the town of Švėkšna in Lithuania.

Four mayor steps are the basis of this scheme:

- Waste stream identification and technology decision in cooperation with the investor
- Practical tests with the selected technology and identified waste in pilot scale
- Discussion and comparison of the practical results
- Financial modelling and cash flow analysis based on results from pilot testing

The stakeholder can afterwards decide if he is willing to invest.

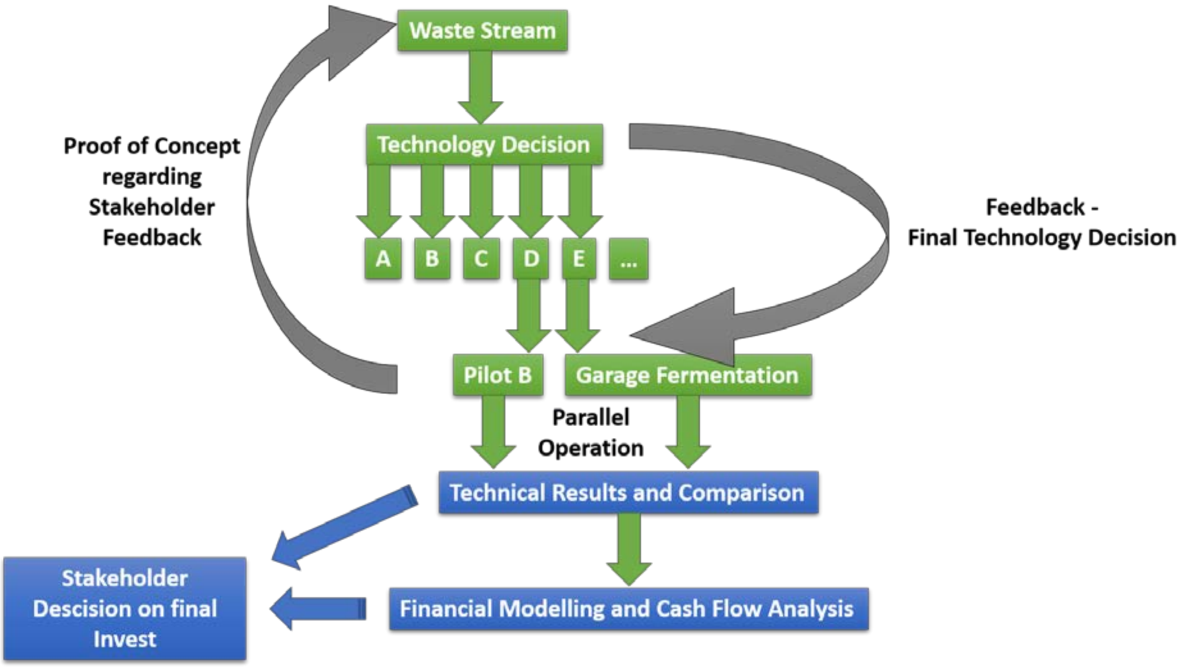

Figure 30: Concept of Pilot plant test process as part of consultancy work.

The following chapters will exemplary describe this process.

4.2 Basic data of Švėkšna, Lithuania

The town of Švėkšna is situated in Western Lithuania. Situated in this town is a mental hospital with a capacity of 250 beds. [22]

The available waste shall come from the town of Švėkšna and from farms in a radius of 10 km. As there are a lot of small farms around the town, the main substrate is cow dung. In addition biowaste collected in the town and in local schools will be added. The amounts will be given later on.

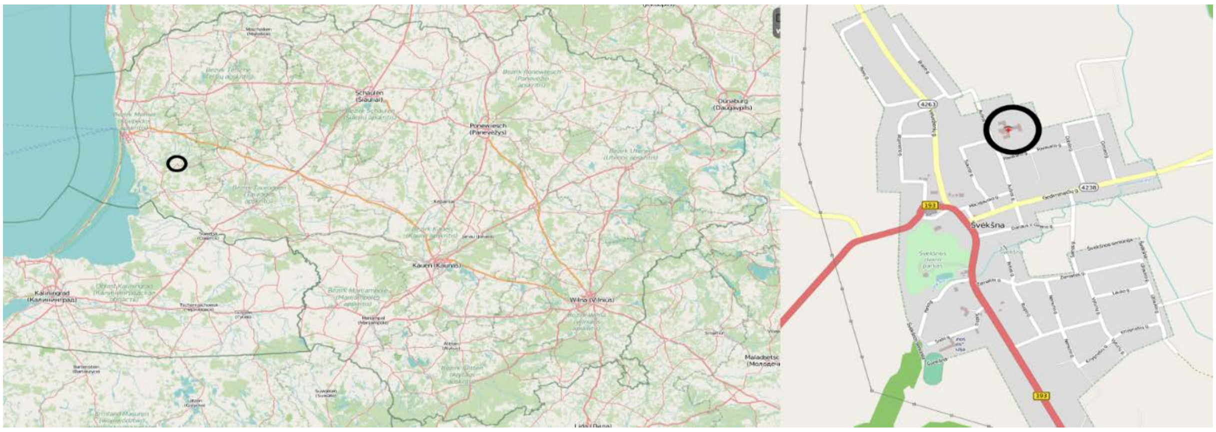

Figure 31: Location of the hospital in Švėkšna, Lithuania.

The assumed location and the area in the range of 10 km can be seen in Figure 32.

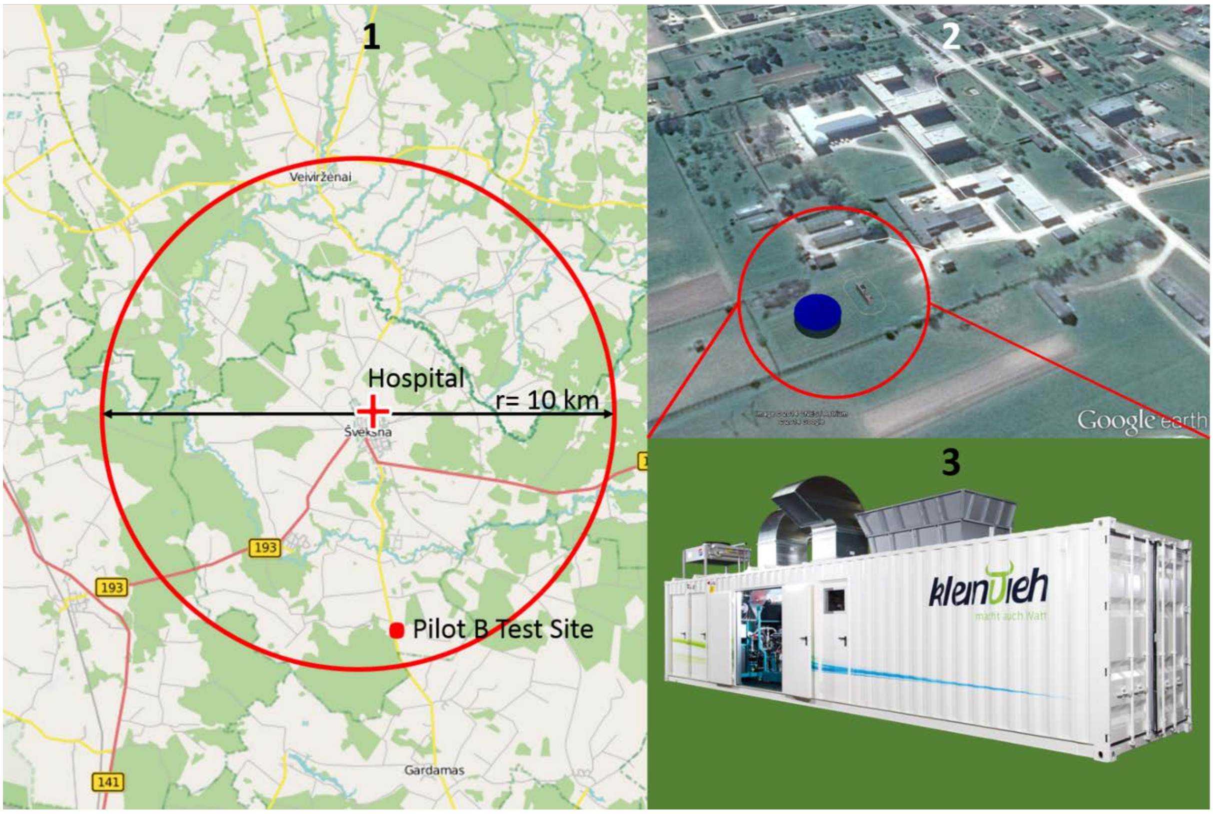

Figure 32: Assumed location for small scale biogas plant. [1] 10 km radius around Švėkšna Hospital. [2] Location of 75 kW small scale biogas plant next to the hospital (3D-modell with kind permission of CJB Energieanlagen GmbH & Co KG, www.kleinvieh.eu, picture from Google earth/CNES/Astrium). [3] 75 kW small scale biogas plant "Kleinvieh" (Image courtesy of CJB Energieanlagen GmbH & Co KG).

The task is now to determine the waste amounts that can be used in the biogas plant. During the project this data has been gathered. Also batch tests have been performed in order to determine the specific biogas yields. The numbers are given in Table 24.

Table 24: Substrate amounts and methane yields for Švėkšna calculations.

	Cow dung	**Food waste**
Available amount	6000 Mg/a	105 Mg/a
Methane yield	30.84[2] [Nm³/Mg(FM)]	85.23 [3][Nm³/Mg(FM)]
Estimated oDM content	20 %FM	
Resulting annual methane volume	193,989 Nm³/a	

The availability of cow dung lies between 4,000 – 8,000 Mg/a, the average of 6,000 Mg has been used in these calculations.
For the food waste, which has a very high biogas potential due to its' high amount of organics, has been assumed from 27 kg/a * inhabitant with 3350 inhabitants for Švėkšna. The rest of the 105 Mg/a comes from schools and kindergartens in town.

As it is unlikely to happen that the farms in the region will disappear, the long term availability of the main substrate can be assured.
The farms are also necessary as a consumer of the digestate, which will give them a product with enhanced fertilizer qualities.
Within the range of max. 10 km it should be economic to transport the manure/digestate. The digestate storage at the plant site can also be seen as an extra buffer for manure/digestate storage, as the output of fertilizer is not possible/allowed the whole year.

[2] Laboratorial Journal No. Lit 06, REMOWE Project
[3] [3]

4.3 Technical issues

Important for the technical dimensioning of the plant is the available substrate amount. Furthermore some assumptions have to be made, considering some technical numbers.

Table 25: Assumptions for up scaling calculations

Full load operating time CHP unit	8,760 h/a (7,900 – 8,200 h/a realistic)
Electrical Power CHP unit[4]	75 kW
Electric efficiency CHP unit	37 %
Thermal output CHP unit	95 kW
Thermal efficiency CHP unit	46.8 %
Energy content methane	9.97 kWh/m³
Organic loading rate fermenter	5 kg(oDM)/m³*d

The operating time of the CHP unit in these assumptions does not consider maintenance or repair time which is not realistic. The time has been chosen anyhow to pretend maximum workload.

As we have these numbers available the calculations for dimensioning of the plant can start.

$$V_{fermenter} = \frac{m_{substrate} * w_{oDM}}{oLR * 365\ d} = \frac{6.105\ Mg * 0.2 * m^3 * d * 1{,}000\ kg}{5\ kg(oDM) * 365\ d\ Mg} \cong \underline{670\ m^3}$$

A higher loading rate would reduce the fermenter volume, a lower one would need a bigger fermenter. Additional space is required as gas storage.

The theoretical accessible methane volume is given in Table 24. From the data given in Table 25 we can calculate the amount of methane that is needed by the CHP unit in full workload.

$$W_{overall} = P_{CHP} * t_{runtime,CHP} = 75\ kW * 8{,}760 \frac{h}{a} = 675{,}000 \frac{kWh}{a}$$

With the efficiency of the CHP unit, the true energy demand (from the biogas) can be calculated:

$$W_{biogas,demanded} = \frac{W_{overall}}{\eta_{CHP}} = \frac{675{,}000\ kWh}{0.37a} = 1{,}775{,}675 \frac{kWh}{a}$$

With the energy content of the methane the necessary methane volume can now be calculated:

$$V_{methane} = \frac{W_{biogas,demanded}}{W_{CH4}} = \frac{1.775.675\ kWh\ m^3}{9.97\ kWh\ a} = 178{,}102 \frac{m^3}{a}$$

As we theoretically have approx. 10% more methane available as results from batch test it is enough methane to empower the selected CHP unit. By choosing the maximum workload of

[4] [27] (SEVA-MA 75 BG Kompakt-Serie MAN (Hu = 6kWh / Nm³ / NOx < 500mg /Nm³)

the CHP unit, there is even more buffer in case that the biological process is working worse than expected.

It can be expected that there will be a similar amount of digestate leaving the process as enters the fermentation as substrate. This digestate can be handled similar to the manure which would go to the fields without the fermentation step. A test has been performed in the Ostfalia laboratory to demonstrate the fertilizer qualities as well as the plant compatibility. Figure 33 shows the results of the plant test.

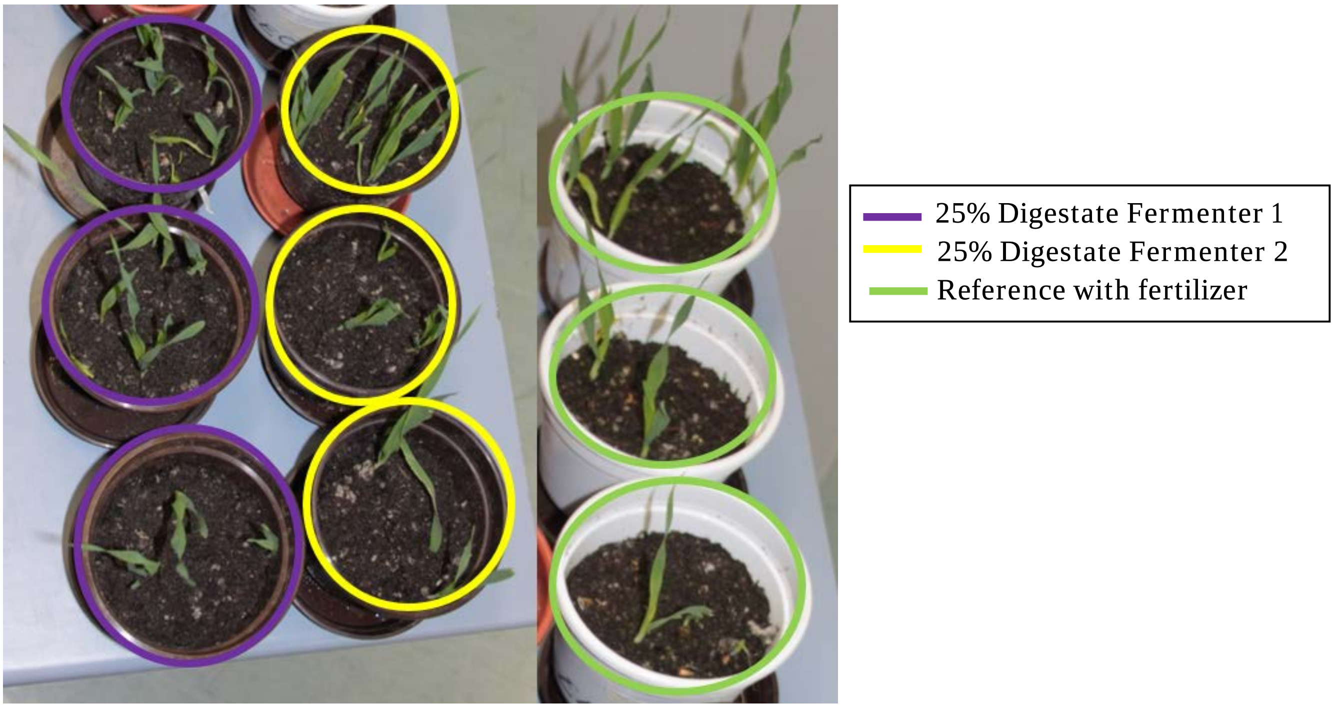

Figure 33: Plant test on fertilizer qualities and plant compatibility of digestate.

The digestate came from two continuous fermenters (Fermenter 1 + 2) running with the same mixture of biowaste (foodwaste) and cow manure. According to figure 33, here has been no negative influence of the digestate recognisable concerning the plant growth.
It should be no problem to utilize the digestate as fertilizer, as this is also common practice in the German biogas sector.

4.4 Financial Cash flow

In this chapter economic issues will be explained in more detail. Only information concerning the cash flow will be discussed. If not marked different, all numbers derive from Lithuanian data.

4.4.1 Revenues

The following revenues from biogas production are possible:
As also mentioned in Chapter 1.4.5

Feed-In Tariffs

The feed-in tariff for electricity from biogas in Lithuania is 0.148 ct/kWh. The feed-in tariff for heat is 0.04 ct/kWh. The produced electricity will be fed-in to 100% while 26.3% of the heat will be used for process heating purposes. [3]

Substrate potential and revenues

A gate fee of 20€/Mg of biowaste has been assumed for the calculations. No revenues are set for the sale of digestate.

4.4.2 Costs

The costs for the investment in the biogas plant will be described in the following.

Investment costs

The specific investment costs for a plant with 75 kW of electrical power amount to [6]:

- 9,000 €/kW of installed electrical power for the whole biogas plant
- 1,700 €/kW of installed electrical power for the CHP unit
- 160 €/kW of installed electrical power for pumps and fittings

Variable costs

Cost factors here are:

- Costs for substrate – no costs for substrate are assumed in this case, but there are revenues from gate fees for biowaste (see above)
- Costs for energy – the price for electricity is 0.145 ct/kWh. As the price is lower than the feed-in tariff, all electricity produced will be fed to the grid. The heat demand will be covered by 26.3% from own production, so that the price for heat will not be taken into account.
- Costs for maintenance and repair – 2.5% of the annual biogas yield will be considered here.
- Costs for transportation – transportation costs are set to 0.1 €/km*Mg(substrate). The radius for transports is 10 km.
- Other costs like e.g. lab analysis or working materials are calculated with 1% of the annual biogas yield.

Fixed costs

Invest related and personal costs belong to the fixed costs.

- Invest related costs – 0.5% of the specific investment costs for insurance, depreciation is set to 2% of the original invest for the CHP unit every 6 years and with 2% every 4 years for the pumps.
- Personal costs – for a plant of this size, a workload of 2 hours per day for one person is set. A wage of approx. 1,000€/month can be assumed.

4.4.3 Cumulated cash flow calculation

The cash flow is a major part in the planning of a biogas plant according to the scheme mentioned before (see Chapter 4.1). The "break-even point" as well as the produced energy for the hospital have to be taken into account.
The energy demand of the hospital can be calculated by the number of beds the hospital offers. With 250 beds the heat demand sums up to 19,800 kWh of heat per year and an electricity demand of 4,650 kWh per bed. The total demand for heat sums up to 4,950,000 kWh the demand for electricity results in 1,162,500 kWh.
The relevant data for cash flow calculation is summarized in Table 25.

Table 26: List of relevant data for cash flow analysis (Švėkšna case).

Income	
Substrate availability: - **Cow manure** - **Biowaste**	 - 6,000t/a - 105t/a
Methane yield: - **Cow manure** - **Biowaste**	 - 30.84 m³ Methane/kg Fresh matter - 85.23 m³ Methane/kg Fresh matter
Feed-in tariffs: - **Electricity** - **Heat**	 - 0.148ct/kWh - 0.04ct/kWh
Revenues from substrate: - **Biowaste** - **Sewage sludge**	 - 20€/t Fresh matter - 20€/t Fresh matter
Costs	
Investment costs: - **Specific** - **CHP** - **Pumps**	 - 9.000€/$kW_{install.el.Power}$ - 1.700€/$kW_{install.el.Power}$ - 160€/$kW_{install.el.Power}$
Price for electricity	0.145ct/kWh
Transportation costs	0.1€/km*t
Labour costs	1.000€/Month

The cash flow calculated on basis of these data is displayed in Figure 34.

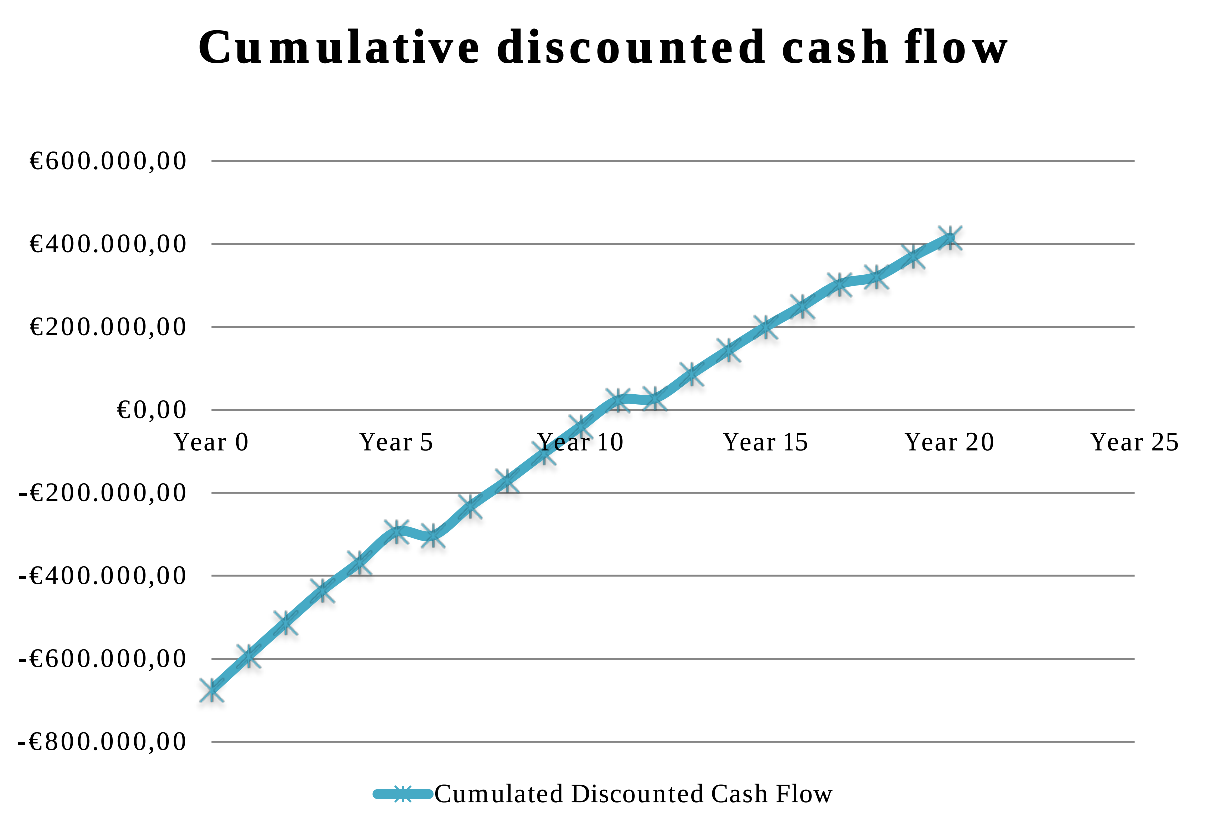

Figure 34: Cash flow for small scale biogas plant in Švėkšna, Lithuania.

The figure shows the cumulated cash flow (invest and profit) over the time of 20 years of operation. In year zero the invest sums up to approx. 700,000€. The "break-even-point" is reached after approx. 11 years.

With an electricity production of 654,950kWh/a and a heat production of 610,548 kWh/a, the plant could substitute approx. 56% of the electricity demand and approx. 12% of the heat demand of the hospital.

5. Summary and Outlook

During the ABOWE project (Implementing Advanced Strategies for Biological Utilization of Waste) a pilot scale plug flow dry digestion system for biogas production has been successfully tested in three different partner countries.

Dealing with different substrates, from cow manure to municipal solid waste, the technical testing periods gave proof of concept of plug flow dry digestion technology. As the project developed, also other types of dry digestion technology came into focus. For example a garage fermentation could successfully be implemented in the work done in Sweden.
Besides being a place of research, the pilot plant worked as a place for learning (knowledge transfer, training on operation) and as well as a demonstrational object for people that had an interest in the technology of biogas production.

The financial aspect of the implementation of biogas in the Baltic Sea Region was another major focus of the ABOWE project. The development of cumulated cash flow calculations went hand in hand with the results from practical on-site testing and the local partners. In a continuous learning process the calculations were developed regarding their influencing factors and its accuracy.

The communication between project partners and potential stakeholders was another issue that had carefully been taken care of. To help keeping everyone up to date, various strategies of marketing and education have been applied. In regular intervals e.g. newsletters have been sent to all partners and stakeholders. The organization of events in every participating country helped to understand the needs of the stakeholders and to keep them informed about the ongoing activities.

There are a lot of possibilities given for future cooperative projects. As already the continuation in case of Švėkšna in Lithuania was mentioned in this report, cooperation with Sweden (Örebro, grass utilization) and Poland (Wrocław, MSW digestion with garage fermentation) are being discussed at the moment.

Together with the other pilot plant (Pilot A, mobile bio refinery) that has been utilized in this project, multiple opportunities for joint test runs can be thought off. Using these two technologies together could lead to greener production of e.g. chemicals while utilising the waste stream for the coverage of own energy demands by biogas production.

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