

# INPUT FACTORS FOR SUCCESSFUL IMPLEMENTATION OF DECENTRALIZED BIOENERGY PROJECTS IN PRACTICE

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**Abstract**—Long-term success of decentralized bioenergy projects in practice is not only based on reliable plant management by well-informed and attentive operators, but is heavily dependent on initial choice of appropriate technology and precise assessments during the planning phase. Learning from failed projects can be as efficient as learning from success stories. All decisions should be based on a detailed assessment of economic viability, a precise evaluation on how the plant fits into existing infrastructure and current site management, and sufficient understanding of the relevant technical and regulatory implications.

Keywords-bioenergy; anaerobic digestion; planning phase; decision process; success factors

## I. INTRODUCTION

Bioenergy with utilization of biomass from forestry and farming, and of organic wastes, holds significant potential to contribute towards a higher share of renewable energy.

Each bioenergy project is unique. While planning for centralized plants at larger scales can to some extent be based on standardized procedures, decentralized small-scale units require particularly site-specific assessment in order to result into economically viable and long-term successful installations. This typically is the case for anaerobic digestion plants at farm scale, where in most cases the farmer does not only partially carry out the planning himself/ herself, but also takes decision for simplified technology adapted to site or substrate specific needs in order to reduce overall costs. Sustainable integration into overall farm management and into long-term planning for the whole site is a prerequisite.

This presentation highlights factors relevant for successful implementation of decentralized bioenergy projects based on looking at the anaerobic digestion technology and compiling knowledge as observed in practice and gained through consulting activities. Its aim is to raise awareness for relevant factors in such projects. Attention is drawn here on the information provided in the section "Acknowledgment". To a considerable extent (where not indicated otherwise in the following) the contents are also available as part of the final report of a research project [1]. However, availability in the focused form of this presentation is expected to be of benefit both for planners and for future plant operators.

## II. DECENTRALIZED AD

### A. The Process

Anaerobic digestion with biogas production is a well-established technology, but with high potential for more widespread implementation in Europe and elsewhere. In the EU, at least 25% of all bioenergy in the future can originate from biogas, produced from

wet organic materials such as: animal manure, whole crop silages, wet food and feed wastes [2].

Anaerobic digestion (AD) with biogas production makes use of a naturally occurring anaerobic process and supplies a controlled technical environment (favourable environmental conditions for the groups of microorganisms involved, including absence of free oxygen, control of temperature) that allows catching and utilising the gases produced for energy generation. AD with biogas has the potential of producing green energy like power, heat or vehicle fuel. In addition, digestion of manure is currently the most promising way to tackle climate gas emissions from agriculture and especially from animal and dairy production. Additionally added organic wastes and energy crops can boost the gas yield, while at the same time AD contributes to successful regional waste management schemes.

An AD facility typically consists of the substrate storage and pre-processing unit, the actual digester(s), storage unit(s) for digestate, and gas valorisation. The degree of complexity of the whole plant and of individual components varies with the size of the AD facility and the substrates. Solid substrates in most cases require pre-processing. Diversified equipment is available on the market, however the technically informed future plant operator (or with help of a specialized consultant or independent planner) can significantly reduce investment costs of decentralized small-scale AD facilities by replacing standardized equipment with more simple installations which might not need any service of the commercial AD plant supplier. One example is decision in favour of a heated reception and mixing pit which offsets necessity of a commercial solid substrate feeder.

Fig. 1 and Fig. 2 provide examples of two typical farm-based AD facilities of different sizes (capacities), with the first one being an option recommended for decentralized units.

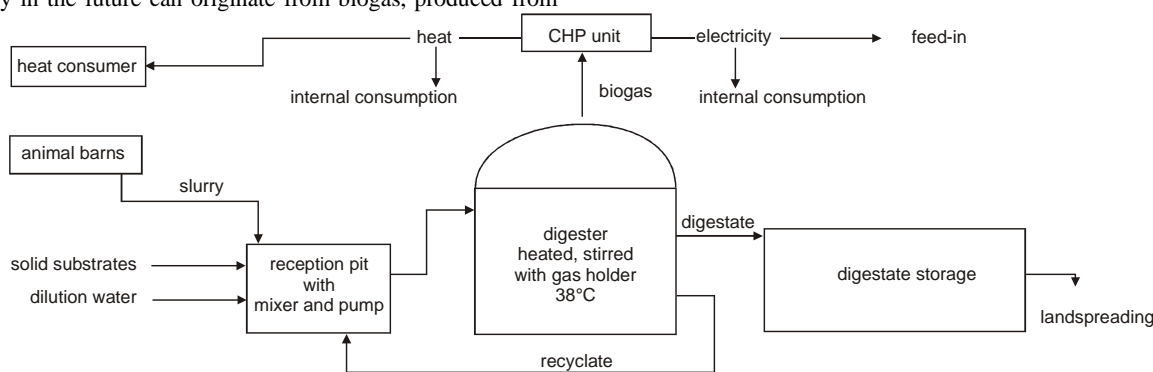


Figure 1. Small-scale (up to range of around 75 kW) AD facility with minimum equipment for digestion of slurry/ manure and a limited amount of solid substrates (e.g. grass); recycle is used in order to reduce the necessary amount of dilution water to assure favourable water content in the digester [1]

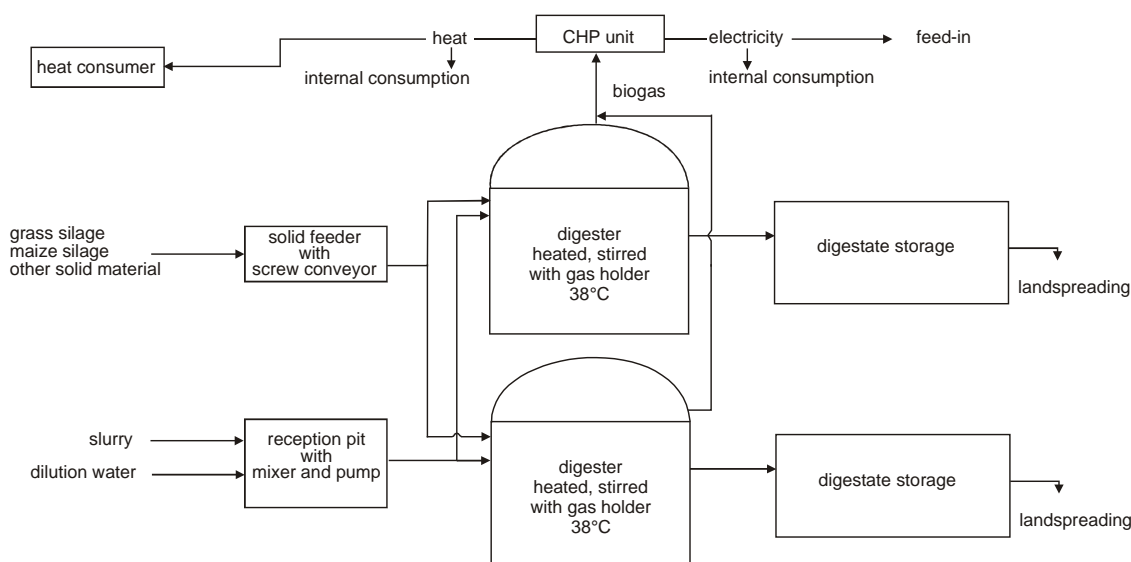


Figure 2. Example of a larger-scale (around 500 kW) AD facility with minimum equipment for digestion of slurry/ manure and solid substrates [1]  
Figure 3.

### B. Valorisation of Outputs

Anaerobic digestion creates two main types of output: biogas which is rich in energy and digestate which is rich in nutrients but may also contain harmful substances. Biogas can be converted to useful energy in different ways:

- gas boiler for use of heat on site
- conversion into electricity exported to the grid and local heat via CHP on site (or pipe to remote CHP)
- vehicle use or injection to the gas grid after cleaning the biogas to methane

With a Combined Heat and Power Plant (CHP), heat and electricity are generated simultaneously. Fueled with biogas, this environmentally friendly technology is even more favourable. Biogas is burned in a combustion chamber which produces a flow of hot air that drives prime movers; a generator converts this rotational energy into electricity. CHPs are based on gas or dual fuel engines. With the last, it must be considered that additionally to the gas a specific amount of ignition oil is needed, to ignite the gas. This is to be considered as additional cost factor. However, dual fuel engines can be operated in case of a breakdown of the biogas supply with pure ignition oil, which prevents operational failures of the biogas plant.

CHP is the most common valorisation pathway for biogas – especially at small to medium-sized installations. A CHP unit is particularly suitable at an AD plant, since some of the generated heat can be directly used to maintain the digester temperature. Exhaust heat can be pumped out through insulated pipes, to provide space and water heating for local buildings. Heat which cannot be used must be dissipated. Only heat which is used by consumers (others than the AD plant itself) has an economic value for the AD plant operator, as it has the potential to replace other ways of heating such as heating with oil or natural gas, or electric heating.

While landfill gas is mostly converted to electricity alone (there is no significant heat demand at landfill sites), AD reactors require heat input and combined heat and power generation is the more favourable option compared to electricity generation alone. The efficiency of CHP units at electricity generation is almost at the level of conventional generators and their overall efficiency degree is higher due to the co-generation of heat energy which is at least partially used.

Sometimes cooling is also produced ('trigeneration': electricity, heating and cooling). Here, some of the heat drives absorption chillers producing cold air for air conditioning (used e.g. for local buildings or

pig units in hot summers). The exhaust heat of the CHP unit is low grade energy, and the energy content is not enough to achieve the low temperatures required for example for cold stores ( $< 8^{\circ}\text{C}$ ). However, new technologies are under research and development.

Combustion solely for heating purposes (no electricity) is done at some very small plants in Europe and elsewhere. Generation of heat alone will in most cases not be the most favourable option, as even very small plants easily generate more heat than required. In case of potential heat demand it might however be an option.  $1\text{ m}^3$  biogas with a methane content of 55% has the energy content of 0.55 litres oil.

For use as either a vehicle fuel or for injection into the network the biogas has to be cleaned and upgraded. Upgrading to biomethane currently is only viable for large-scale AD facilities (MW range, not kW range).

The second main output of AD is digestate, which contains the non-metabolized constituents of the substrates. If the digestate can be spread to land, its fertiliser value adds a benefit to the AD installation. AD results in a digestate with an improved fertiliser value, with excellent potential to displace mineral fertilisers. Compared to direct utilisation of animal manure AD digestate is much more predictable in its fertilising effect, as the anaerobic process converts organic nitrogen into ammonia. In raw animal manure 30-50% of the nitrogen is in organic form and must first be mineralised for plant uptake. AD digestate also minimises leaching losses – when spreading manure, nitrate is a significant pollutant.

Digestate is rich in nutrients but it may also contain harmful substances. Fertiliser value of useful digestate increases economic viability. Digestate which cannot be spread to land must be disposed of, which implies additional costs.

## III. THE PLANNING PHASE

### A. General Considerations and Pre-Planning

Biogas production reduces greenhouse gas emissions and contributes to an environmentally sound waste management treatment concept. Every well-run biogas plant contributes to fight the global warming and reduces pollution of the environment. In addition to the positive environmental aspects, an economically viable biogas plant is a source of additional income for the operator. If well integrated into the farm concept, it is to be expected that the biogas plant has mostly positive interactions with the rest of the farm business. This includes the supply of feedstock, provision of digestate offsetting fertiliser cost,

use of labour in slack time of the farming year and cheaper supply of heat.

Investment in a biogas plant is long-term fixed and should be carefully assessed. It is not possible to fix a financially stricken farm business through a biogas plant. For the project financier, which is usually a bank, not only the usual credit examinations as credit-worthiness, solvency are of crucial interest, but also the technical feasibility and especially the assessed economic viability of the planned plant, and as well the integration of the AD project into the business shape.

In order to make a sustainable decision, a potential biogas plant operator should be well-informed about technical issues, biological issues, financial aspects and regulatory framework implications. In addition to information from literature, the future plant operator can participate in study tours or in a biogas training course. A future biogas plant operator should be well aware of the fact, that no AD plant is a stand-alone unit but it will require continuous attention.

The planning of the plant should be as detailed as possible and sufficient time should be allowed before taking decisions. The situation of the farm business should be analysed in detail and the future biogas plant operator should have information about the available technical systems on the market and about the different configurations of the installations. Conversation with several providers should take place. Available substrates should be determined as precisely as possible because they are the basis for the further planning process, including the necessary approval procedure and the offers from biogas plant suppliers. A detailed feasibility study is favourable prior to taking decisions. Analysis of the available substrates such as chemical analysis and determination of the potential biogas yield provide a better planning basis.

The potential future biogas plant operator should try to gain detailed knowledge about the biogas process and the technology, in order to be able to make a sustainable decision if a biogas plant fits into the farm concept and if yes, which technology will be best suited. Depending on the country, companies with many years of experience and a significant number of reference projects offer AD concepts which have proven to be reliable. As there is constant development in the AD sector, new concepts might also be worth to be considered – but they include higher risks. It is generally beneficial to decide in favour of technologies from companies which provide support and process guarantees. The percentage of operating time of the CHP unit is crucial. [4] assessed that full support from the technology provider raises the generator running time from an industry average of 65% to over 90%.

Co-digestion of wastes could make a useful contribution to operation of on-farm AD plants e.g. in the UK, while at the same time this contributes to sustainability by returning the digestate back to land as part of the nutrient cycle [4]. An agricultural plant operator needs to decide if he/she is willing to take in wastes to the farm. Co-digestion of food waste will bring the plant under different legal frameworks, e.g. in the EU under ABP (Animal By-Product) regulations, which require pasteurisation of the materials. Treatment of wastes therefore needs extra equipment. Besides higher investment costs (mainly due to necessary hygienisation technology), co-digestion also requires more regular analysis of the AD process. All incoming wastes need to be controlled. However, co-digestion of wastes can be beneficial due to two revenue streams: increased gas yield and gate fees. Gate fees will vary according to waste type and local or regional outlets. Long-term contracts for taking in waste materials are favourable.

#### *B. Integration into Existing Infrastructure*

Wherever possible, existing infrastructure should be used. This might be storage for substrates or digestate, existing roads, transport equipment, facilities for spreading digestate etc. Demand for heat on site or e.g. by nearby villages or facilities should be evaluated and

considered as promising option to further increase economic viability. Transport of gas to sites with heat demand via micro gas grids might be a particularly favourable option compared to supply of heat [5] [6].

When looking on-farm, most AD plants will use slurry or manure as one substrate. When barn systems are newly established, some aspects relevant for biogas production should already be taken into account. The use of flush systems to remove the manure from dairy barns can have economic advantages within the dairy unit and is less labour-intensive than other systems. In addition, flush systems remove practically all of the manure, while water-free systems do not clean the barns as efficiently. However, dilution of manure with water will require significantly larger and therefore more expensive AD facilities. Dilution can also increase the stratification risk within the digester, with straw or other lignocellulosic material forming a thick mat on top, while sand accumulates at the bottom [3]. Scrape systems are more favourable. They collect the manure by scraping it to a sump without changing its consistency.

Slurry should be fed directly into the digester. The common storage place under the barn is therefore unsuitable as a pre-storage space, and for after-storage as well as degassing can continue after digestion (harm to animals). A weeping wall or other solid phase separation process is also not necessary. Any gravity separator will remove an amount of degradable organic material that could be converted into biogas. In addition, the separation process alters the carbon to nitrogen ratio of the streams. While a significant proportion of the organic carbon is retained with the solids, an equal percentage of the nitrogen and phosphorus is not. Up to 80% of the COD and 30% of the total nitrogen and phosphorus can be found in the solids removed by a screen and sedimentation process [3].

If possible and economically feasible, the farm management should strive to use within the barns litter material favourable in the digestion process. Woody material does not generate significant amounts of biogas. Straw is more favourable than wood shavings or sawdust. Straw should be chopped prior to using it as litter material in the stable. Sand will clog pipes, damage equipment and fill the digestion tank. Slurry retains sand that precipitates in the digester when organics are degraded and the solids concentration is reduced. If the presence of sand cannot be avoided, equipment for sand removal needs to be foreseen in the AD concept, which increases the necessary investment costs. With sand accumulating at the bottom of a fermenter, the effective digester volume will continuously be reduced, which can have negative effects on process stability.

#### *C. Assessment of Economic Viability*

A detailed assessment of economic viability of the planned bioenergy facility is essential. The assessment should be carried out by a specialist who's calculations will be accepted by the bank or investor – prior contact to the financier is suitable, or decision in favour of a registered specialist (in case registration schemes are available in the country).

When contacting biogas plant suppliers, the future operator will often receive a preliminary assessment of economic viability of the planned plant. In most cases this should be regarded as too little detailed, and will not contain all relevant cost factors (such as necessary infrastructure, connection to the grid, storage, earth works). While offers of some companies might cover full costs and might also indicate necessary earth works etc., other companies include costs for the actual plant components only. When comparing different offers, it needs to be ensured that all relevant cost elements are included in the final prices. In cases where relevant cost elements are not included in one offer, those additional costs need to be added for comparisons and final assessment.

The two major costs associated with a biogas plant are the initial investment costs (set-up of biogas plant, including planning costs, costs for approval, grid connection, etc.) and the ongoing costs

(substrate costs, maintenance, insurance, labour costs, spreading of digestate, etc.). On the income side, revenues from four sources at the anaerobic digestion facility are relevant: sales of electricity, utilisation of excess heat from the CHP unit, fertiliser value of the digestate, and gate fees for the treatment of wastes (if any). Economic viability of AD plants depends on several factors, including:

- scale (capacity) of the biogas plant
- amount and continuity of available slurry and manure, housed time of breeding stock
- availability of energy crops and their specific costs
- production of waste on site
- policies and regulations when treating other wastes
- favourable approval conditions which can be fulfilled at reasonable costs
- gate fee which is charged or paid for waste
- value of bio-fertiliser
- the market value of generated electricity
- possibility of on site heat use, and income from heat
- reasonable investment and building costs

- already available equipment or buildings that can be integrated in the biogas concept
- availability of grants

Required minimum digestate storage capacity needs to be considered as cost factor. Careful assessment of available substrates with their potential biogas yields is among the most relevant factors when evaluating economic viability of a project. Energy crops might be attractive in order to underpin biogas generation from other substrates, but it needs to be taken into account that they require additional investment in feedstock storage, which reduces the possible benefit.

Aside of annual business profit or loss, the payback period is the most relevant economic decision factor (Fig. 3). A detailed economic assessment and profitability projection should include a sensitivity analysis to highlight the most influential factors and the degree of uncertainty. Suitable parameters for the sensitivity analysis are: efficiency of CHP unit, gas production, investment costs, revenue from electricity.

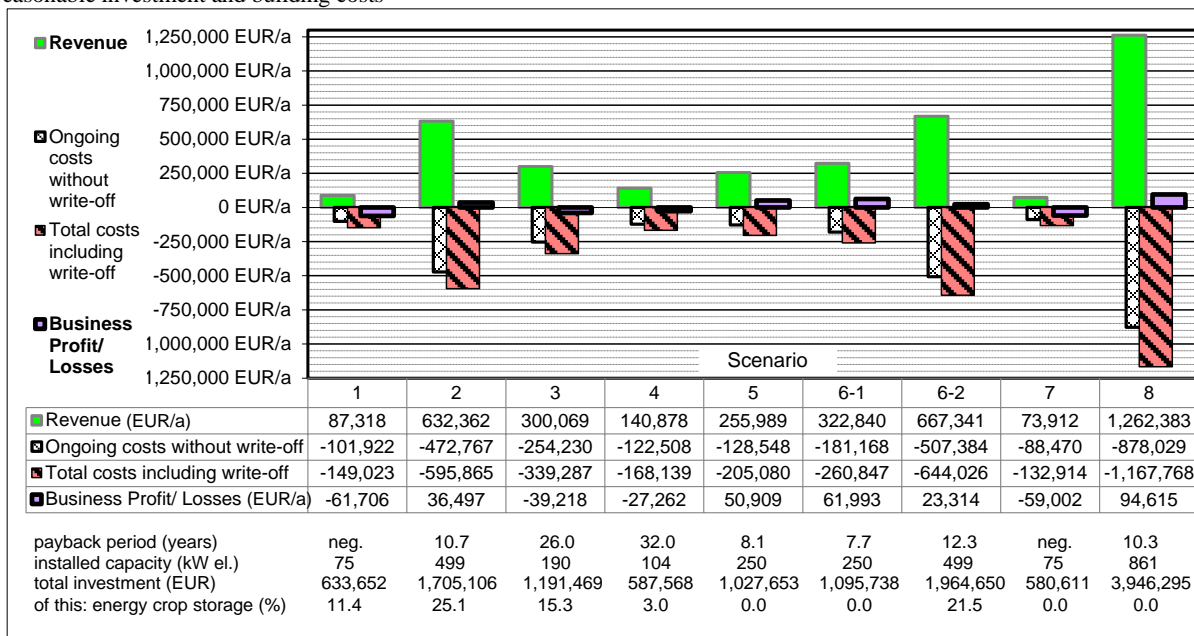


Figure 4. Example of key data resulting from calculation of economic viability for different options (adapted based on [1])

#### D. Regulatory Framework and Approval

The future biogas plant operator should be aware of the relevant regulatory regulations and the necessary licences. It is important to contact the Local Authority Planning Department at an early stage and involve them in the selection of the location, types and amounts of substrates and wastes involved, transport movements, and details of the process. The Local Authority will assess the application and might carry out a consultation with local stakeholders. Good cooperation with the Local Authority will facilitate the approval procedure.

Concerning connection to the electricity grid, the regulations vary for different countries. Contact with the relevant authorities in the early development stages of a renewable energy generation project is extremely important to ensure that the desired connection date can be met. Decision can easily take several months. Feasibility studies might be carried out, and grid reinforcement might be found to be necessary. For connection to the grid, especially in cases where feasibility studies are carried out to assess the suitability of the grid, a higher capacity should be applied for during the planning phase than the actual calculated capacity of the installations. If the anticipated capacity of the AD facility increases during the project planning phase or later

during the completion phase, e.g. due to inaccuracies in the first assessments, due to more substrates being available after changes in the farm management, due to additional substrates being available at neighbouring farms or due to the decision to take in wastes, it will be more favourable if the higher capacity is still covered by the feasibility study and any reinforcement of the grid. Otherwise the procedure process would need to be restarted which will cause additional costs and delays.

For small farm-scale biogas plants, it seems reasonable to apply for a capacity which is at least 25% higher than the anticipated power output of the facility. In case of high uncertainties it might be suitable to apply even for a higher capacity. There might be some additional costs in this procedure, as the feasibility study might be more expensive and also the necessary grid reinforcement might be higher. However, there will be no technical problems to connect a facility when the actual capacity is smaller than the planned one. But if the actual capacity exceeds the planning figure the connection might be refused and it will be re-assessed if additional reinforcement of the grid is necessary. All expenses so far still need to be settled and the

restarted connection process will result in additional costs. The delay might be even more significant.

The better the potential biogas substrates and their methane yields can be assessed during the planning phase the better is the dimensioning of the AD plant and all accompanying elements, including the connection to the grid.

#### IV. SUCCESSFUL OPERATION OF THE BIOENERGY FACILITY

In order to operate a biogas plant safely and highly efficient, every plant operator must have detailed knowledge about the biogas process. This helps to avoid "feeding errors" and to correctly interpret measurement data. To monitor the process, control of pH values and digester temperature is imperative but it might not be enough. Digestion of co-substrates in general requires more attention and additional analytical routines, while AD processes run on manure and slurry are more robust and less susceptible to failure.

Contact to other plant operators and exchange of knowledge are beneficial. "AD neighbourhoods" with regular meetings and provision of support when necessary strengthen the individual site and facilitate dealing with any problems.

An AD plant is a long-term investment. It needs to generate revenue over many years. While keeping the running costs as low as possible, the biogas plant operator should concentrate on maintaining high process stability and high gas production. Fewer gas generation and lower efficiency of the CHP unit can significantly reduce business profit. The AD plant needs attention and labour on a regular basis. Any failure or inhibition of the biological process or a temporary break-down of the CHP unit will result in reduced revenue.

As a rule of thumb goes that the necessary annual labour is between 4 to 5 hours per installed kW. This is the necessary labour for the actual plant operation, and does not include activities such as production of energy crops or spreading of digestate. The higher the complexity degree of the plant the more labour is necessary. Some automation is possible at larger plants, but no biogas plant can run fully automated. Slurry based plants require the lowest amount of effort and labour. Handling of different types of materials requires more time.

The operator must also be aware of the fact that in case of illness another well-informed person must be able to ensure at least the basic regular biogas plant operation.

The technical equipment needs maintenance. Regular maintenance especially of the engine should be carried out. Major biogas plant maintenance should preferably be carried out by avoiding the winter period. The winter months offer a higher heat utilisation potential. Moreover, in general more slurry is available for treatment during this time.

It is more favourable to allow labour time on a routine basis than to be obliged to deal with problems. The biogas plant operator should be constantly aware that problems with both the technical equipment and the biological process can occur. Process imbalances not only

reduce energy generation but also require extra attention and extra labour time.

In order to avoid process failure, the process stability should be monitored and the plant performance should be regularly assessed. On-site analyses or external laboratory analyses may seem expensive, but are an important element in achieving and maintaining a high plant performance. AD processes run on slurry/ manure basis in general show high process stability and very low risk of process imbalance due to the buffering characteristics of the substrates. Shortage or lack in slurry results in digestion processes which are more susceptible to biological imbalance and hence require more attention and regular analysis.

#### V. CONCLUSIONS

Successful decentralized bioenergy generation – as studied in this presentation based on the anaerobic digestion technology – holds significant potential to contribute towards a more sustainable national energy concept. At the same time, digestion of slurry, manure and organic wastes, and where possible co-digestion of energy crops such as grass, maize, whole crop silage, can become a source of additional income for farmers. In addition, anaerobic digestion improves the fertiliser value of the processed substrates and significantly reduces odour emissions.

Careful decision makings in the planning phase with a detailed economic assessment based on a careful assessment of available substrates, suitable technology including possible reduction of complexity in order to reduce investment costs but without putting reliability at risk, and integration of the facility into the whole management at a specific site are among the main success criteria.

There is widespread consensus that decentralized bioenergy facilities have the potential to strengthen rural areas and at the same time offer opportunities for a specialized industry. Advice and assessment by independent experts is especially suitable during the planning phase.

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