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Renewable Energy &
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Final Report:

Renewable Energy and Waste Management in Ghana

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Contents

0. Summary

Dry anaerobic digestion has been implemented successfully for a number of years in Europe. Experts report that this process has a high potential of success for application in developing countries as it has a very simple design which can be constructed and operated at low cost, does not need addition of water, and the residues after digestion can be more easily treated in a safe way. Nonetheless, there were no documented experience with this technology used in a developing country context. Eawag in collaboration with KNUST and ZHAW developed a dry anaerobic digester with locally available materials by converting a second-hand shipping container into a biogas plant. With this technique, the organic solid waste is filled batch-wise into the digester where the material remains for a duration of 1-2 months. By a percolation system, water is circulated in order to spread the anaerobic bacteria evenly in the feedstock.

The pilot plant at KNUST was operated during one year and four batch runs have been conducted. Organic material from the solid waste dumpsite in Kumasi with a high fibrous content and fresh cow dung served as feedstock. The first batch test revealed that the container was insufficiently airtight and no satisfactory biogas production could be reached. After several modifications and further batch tests with unsatisfactory results, a second biogas digester was constructed using a shipping container of higher quality. Finally, the fourth test run showed an increasing gas production and a methane content of 55-60%. However, gas production levels still are not as expected.

The following reasons are postulated why the biogas production is lower than expected. First, the nature of the feedstock might not be ideal for anaerobic digestion due to its high cellulose and lignin content. Although this material allows the percolate to penetrate the feedstock uniformly, it is not easily degraded by methane-forming bacteria. Secondly, it proves difficult to estimate if the digester is airtight. This issue was difficult to verify as the gas flow meter was not able to measure low gas flow rates.

After the experience in Kumasi it can be said that dry anaerobic digestion in theory is suitable for developing country context, but there are still several technical problems that have to be solved. A major challenge is the air-tightness of the digester, as in comparison with the continuous wet fermentation, it has to be opened and closed regularly. Further tests are also necessary in order to know more about the ideal substrate for the dry digestion process. A clear advantage is the easy handling of the digestate as it is stackable and can be used as compost after a post-treatment period. Further research is needed in order to optimize the biogas digester and to reach a satisfactory biogas production.

1. Objectives

Overall objective

- Contribute to the development of appropriate technology for renewable energy production in Africa.
- Contribute towards greenhouse gas reduction.
- Contribute to an improved solid waste management by anaerobic treatment of the organic fraction.

Specific objective

- Explore the possibilities for construction of dry anaerobic digestion systems in developing countries using local materials.
- Develop, build and operate a dry fermentation digester which is appropriate for Ghana and has potential for replication in other developing countries.
- Explore the possibilities and opportunities for small scale CDM projects in the waste sector.
- Dissemination of innovative biogas technology for urban areas of Africa.

2. Technical Solution / Applied Method

Dry fermentation - discontinuous process with percolation

In the discontinuous dry digestion process, a predefined amount of waste is filled batch-wise into simple garage-like digester with an airtight door. All degradation phases take place in just this one fermenter. As a general rule, the fresh material is inoculated with old material from a previous digestion batch or with cow dung in order to accelerate growth of anaerobic bacteria and rapid methanogenic degradation. Once the door is closed, it remains closed throughout the digestion phase and the content is neither transported nor turned.

The digester has a percolation system which on the one hand collects leachate from the pile of waste and on the other hand allows recirculation and sprinkling of the waste inside the digester. The percolation system operates from the start of the anaerobic phase which then lasts for 4-8 weeks, depending on the characteristics of the substrate. Sprinkling of the percolate may occur continuously or periodically but is stopped a few days before opening the digester to ensure that the material is well drained for subsequent further use. Before opening the digester, the air inside the digester is flushed with exhaust gas from an engine or with ambient air to avoid that an explosive gas/air mixture may arise after opening and while emptying the digester.

The fermentation plant can easily be extended or reduced by one or more digester modules. This allows better control and optimization of retention time to ensure improved gas yield and allow a flexible adjustment of the plant to changing input materials.

This dry fermentation approach has already been implemented successfully for a number of years in Europe. Experts report that this process has a high potential for application in developing countries as it has the simplest design and lower cost than the wet digester reactors. A big advantage of the technology is that no addition of water is needed - often a scarce resource in many countries – and that the residues after digestion can be more easily treated in a safe way. Also, dry digestion is less sensitive to a variety of substrates in their size or the level of impurities they contain. In comparison, in wet fermentation reactors, changing feedstock size and composition leads to severe operating challenges. Although experts agree about suitability of this approach, it has yet to be proven that the dry digestion technology can be developed locally which inherently better adapted and thus more appropriate for low and middle-income countries conditions. It is only with pilot demonstration and research and development including close monitoring that the strengths, weaknesses, opportunities and threats can be analysed, understood and documented.

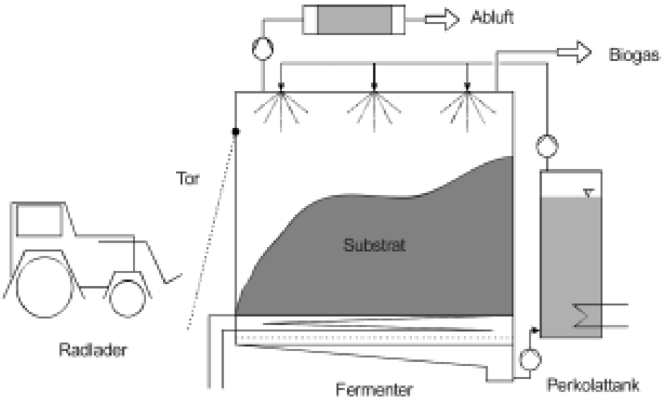

Figure 1. Garage fermenter with percolation

3. Results

In a pre-REPIC phase (December 2010 - May 2011) two Swiss ETH students conducted a preliminary study on-site in the city of Kumasi, working in close collaboration with researchers of Kwama Nkrumah University of Science and Technology (KNUST). They identified and evaluated different local materials potentially suitable for the construction of a dry digestion biogas plant. Based on these findings, the decision was taken to purchase a second hand shipping container. This container has been converted into a biogas digester.

With REPIC funding the project then continued its activities by involving three Swiss and two local students (teaching assistants at KNUST) to streamline and optimise the existing facility. Several research activities were conducted which all contribute to establishing more scientific information for dry digestion biogas development.

3.1 Results from digester operation

Technical improvements at the container

After a first trial with organic waste from the landfill (pre-REPIC phase), it became obvious that improvements were necessary regarding the air tightness of the digester. Main reason for the lacking air tightness proved to be the two wing door of the container. To improve air tightness a garden hose was installed to tighten the two wing door. Furthermore a wooden frame was constructed behind the doors to improve the sealing and combined with bicycle tire which were glued on to the wood where necessary. The bicycle tires were then pumped with air to increase sealing. Silicone sealing was used for smaller leakages. Additionally the silicon was painted with rust free colour to make it last longer.

Furthermore, several improvements needed to be done to simplify the technical handling. Besides also general maintenance to avoid corrosion, ensure longevity and to increase the air tightness. The floor silicon sealing had dried out and needed to be replaced. The inside and outside walls of the container were painted with anticorrosive paint. The percolation system had to be rebuilt as much of the system was clogged by solids and the holes were not large enough for some solids in the percolate to pass. The new percolation system avoided a percolation tank which previously had created problems. A direct connection from the outlet to the filter was constructed: The permanent use of electricity for the percolation pump made the installation of a separate electricity connection inevitable. A new flash back arrestor was constructed like a wash bottle known from the lab. Like this the water level inside is visual and a possible gas flow was detected more easily.

Batch #1

The improved digester as described above was loaded with a standard feedstock (delivered from Zoomlion), inoculated by fresh cow dung from the abattoir and an inoculated percolate that provided appropriate pH-conditions. The percolation was continuously controlled by a time switch. Every day measurement was proceeded for:

- Temperature, pH, Redox potential and conductivity of the percolate (2-3 times)
- Gas flow, gas quality (2-3 times)
- Contents of the produced gas (1 time)

Besides, the COD of the percolate was measured once a week. The TS, VS and COD of the feedstock were measured at the beginning and at the end in the digestate.

After 32 days the container was unloaded, cleaned and maintained as preparation for the following batch. The digestate was dumped on a pile near the fermenter as half of it was used as inoculum for the second batch. The percolate was stored in buckets so it could be used for the next fermentation process. Only little liquid could not be pumped out via hose and had to be drained into the environment.

Table 1. Substrates used for first batch

Compounds	Mass (t)	Density (t/m³)	Volume (m³)
Feedstock	5	0.5	10.00
Inoculum (cow dung)	4	0.9	4.44
Percolate	1	1	1.00
Calcium carbonate	0.003		
Total	10		15.44

During this test run, the pH remained always below 7.5 and was mostly around 6.5, even though calcium carbonate was added with the percolate to increase the pH. This indicates an unfavourable environment for the methane-forming bacteria. As a consequence, the methane content in the biogas was very low and reached only 18% at the end of the test run.

In between the unloading of batch one and the loading of batch two, silicon sealing on the floor and the door was renewed. Rust inside the container was no issue.

Batch #2

For the second batch, the main features of the setup and measuring was not changed. But the material was inoculated differently. The digestate of batch one was used as inoculum, therefore the ratio of the compounds was meant to be 3:1:2 (Old digestate: Feedstock: Cow dung) concerning their mass. In this case feedstock and cow dung are together considered as feedstock for this second batch and represent about 50% of the load, which is recommended by various sources of literature.

Table 2. Substrates used for second batch

Compounds	Mass (t)	Density (t/m³)	Volume (m³)
Feedstock	2.4	0.5	6.00
Cow dung	4.05	0.9	4.5
Digestate batch one	6.3	0.9	7
Percolate	1.5	1	1.50
Calcium carbonate	0.0045		
Total	14.25		19

During the second test run, the pH was again very low at the beginning, but stabilized at around 7.7 after 45 days. Again, calcium carbonate was added to increase the pH. This time, the methane content in the biogas reached a maximum of 50-60% after 25 days, but dropped again to 40% after a few days.

Batch #3

Before starting with the third test run, some adjustments were necessary. After unloading the digester, the digestate was kept aside protected with a tarpaulin in order not to be exposed to the rain. The percolate was pumped out and stored in rubber tanks. The digester was then cleaned and the percolation system tested with water. Some silicone was applied on the container floor to seal the interstices through which the liquid could possibly leak out. Moreover, in order to prevent the surface of the digester to deteriorate, some black anti-corrosive paint was applied on the outer and inner walls of the container.

The substrate used for the third batch was composed as follows:

Table 3. Substrates used for third batch

Substrate	Mass [t]	Density [t/m^3]	Volume [m^3]
Fresh organic waste	5	0.5	10
Digestate	6	0.8	7.5
Cow dung	1.8	0.9	2
Calcium carbonate	5 kg	–	–

During this test run, the methane content reached between 55 and 60%, which is normal for biogas. The pH stabilised between 8 and 8.5, which is in the optimum range for anaerobic digestion. However, no gas production could be measured. This results probably from the fact that the gas meter installed initially had been subjected to corrosion and required consequently a high pressure of the gas inside the digester to be able to measure any gas flow properly. This pressure could not be attained because of the numerous leakages present at the door sides.

Another problem encountered during this test run was that a big quantity of percolate was leaking out of the digester. Consequently some water had to be added to make up for these losses (around 300 litres were added in total during the digestion).

Installation of a new digester

Based on the results and problems faced during the test runs #1-3, a new digester was built. The new digester is also made of a 20ft shipping container. Its design was based on the design of the first digester. It has been equipped with metallic inlet and outlet pipes directly welded to the surface of the container and with systems of PVC pipes for the percolate circulation and for the gas outlet. To prevent the contact with the rain it has been equipped with a roof. During the day, the digester was also directly exposed to the solar radiation. The roof thus helped preventing the temperature difference between day and night to be too elevated.

Furthermore, the digester was mounted on legs. The fact that the digester was elevated prevented the bottom of the container from being in contact with the ground and thus prevented the wooden plates from rotting. Furthermore, the operators were able to easily locate the places where percolate was leaking, allowing them to collect it easily. As for the previous pilot plant, cement blocks were placed under the digester, to create an adequate inclination. This allowed the liquid to accumulate on one side of the digester and to be more easily collected and pumped for recirculation.

Moreover, to prevent percolate from leaking out of the bottom of the digester, fibreglass coating has been applied on the floor. This way, interstices existing between the wooden plates could be sealed. Finally, anticorrosive paint was applied on the inner and outer walls.

The investment costs for the new container amounted to around 8000 USD. Whereas the investment costs for all additional equipment (pump, pipes, valves, filters,...) amounted approximately to 200 USD. All equipment is made of locally available material.

Batch #4

After the installation of the new and improved container, a fourth batch run was started. The substrate was composed as follows:

Table 4. Substrate used for fourth batch

Substrate	Mass [t]	Density [t/m^3]	Volume [m^3]
Fresh organic waste	6	0.5	12
Digestate	6.4	0.8	8
Calcium carbonate	5 kg	–	–

Also during this test run, the methane content reached between 55-60% and the pH value was between 7.4 and 8.5, thus the ideal environment for methane-forming bacteria. Nevertheless, the amount of biogas that could be measured with the gas meter was very little. The 6600 litres in 30 days (see Figure 2) only represents 1.4% of the biogas yield that could be expected.

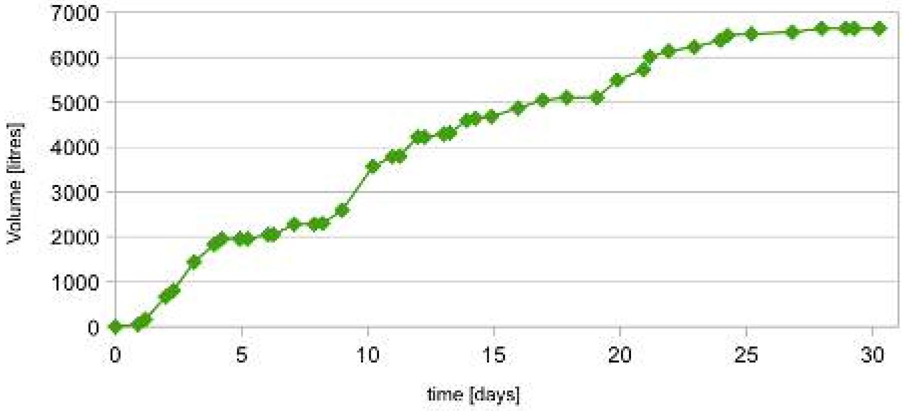

Figure 2. cumulative biogas production during fourth batch

There are various reasons why the biogas production is so low.

First, the nature of the feedstock is not suitable for biogas production. On the one hand, the majority of the waste that was fed into the digester is made of fibrous or cellulose and lignin rich materials. The positive aspect of using this kind of structural feedstock is that the liquid can percolate easily through it, without clogging the outlet pipes and filters, and without becoming too thick and viscous to be recirculated with a pump, allowing the liquid to penetrate in the feedstock. On the other hand, lignin and cellulose rich materials are not easily degraded by methane-forming bacteria to produce biogas. Thus, although this type of feedstock is ideal for percolate distribution through the feedstock, it is not optimal for biogas production.

Secondly, the more the substrate is cut into small pieces, the more easily it can be reached and degraded by methane-forming micro-organisms. The fact that the feedstock is not shredded thus reduces its potential to produce biogas, or reduces the rate at which biogas is produced. Shredding the substrate in small pieces could increase the rate at which biogas is produced but at the same time it could cause difficulties with the percolate circulation system. The collection pipe and the pump filter could more easily become clogged because of the small pieces of substrate.

Third, the micro-organisms that degrade the substrate are mostly present in the liquid (percolate). It can be that the percolate is not uniformly distributed over the whole feedstock and that some parts of the feedstock is not reached by the percolate. After test run #3, when the percolate circulation piping system was dismounted, it could be observed that some holes of the sprinkling pipes were clogged. This could lead the percolate to wet the feedstock at some determined places only and form some channels in the feedstock through which the liquid flows. If the liquid is not distributed evenly throughout the feedstock, some parts are not in regular contact with the percolate. In consequence, the biological activity is not maintained in those places.

Finally, it can be that not all the gas produced is actually measured by the gas meter. On the one hand, some gas could be leaking out of the digester. Although the digester has been improved in comparison with test run #3, the airtightness of the digester still remains an issue. This fact however can hardly be verified and has not been measured. On the other hand, the instrument measuring the gas flow has a detection limit of 40 litres per hour. Any gas flow lower than that is not detected by the gas meter. The biogas could at some points be flowing out at a lower rate than detection limit of the gas meter and could then in consequence not be measured.

3.2 Operational guidelines

To guarantee the implementation of the biogas fermentation at KNUST it is important to have documentations about the techniques in use. Therefore a user manual was developed to help operate the technical aspect of the present system. As it is not only important for future implementation than also to guarantee a seamless handover of the project between the single studies, that will follow within the project continuation, a documentation in form of a user manual will be helpful.

The user manual was divided in the following major parts:

1. Introduction
2. Preparation and assembly
3. Loading
4. Reaction observation, treatment and troubleshooting
5. Unloading and post-treatment

The user manual is written for people which handle the fermenter but have no previous knowledge of biogas digestion. Explanations are as simple as possible to keep the eye on the important factors as the understanding of the system and the process observation.

The user manual is part of the publication *Biolley and Diggelmann (2011)* in Annex E.

3.3 Economic viability

A detailed cost-benefit analysis has been elaborated by *Burri and Martius (2011)*. The financial analysis depends on different assumptions that greatly influence the economic performance. Factors such as the electricity tariff, the availability of substrate material and its transport distance or the market value of compost can vary greatly. Therefore different scenarios were developed to account for possible variance.

A “baseline” scenario assumes a modest feed in tariff of 12 cents/kWh for electricity, no heat usage, modest avoided landfill costs (4 US$/tonne, this equals the amount the government pays to manage waste at a landfill, and a very low market value for compost (10 US$/tonne).

In a “low-revenue” scenario, it is assumed that the electricity is sold at the current market price of 8 Cents/kWh, avoided landfill costs are zero, process heat cannot be utilized and compost has no market value.

In a “high-revenue” scenario, a feed-in tariff of 23 Cents/kWh for electricity is assumed, avoided landfill cost are high (8 US$/tonne, this assumes that the government subsides organic waste recycling), process heat can be used partly (15 Cents/kWh) and compost sales at 40 US$ per ton roughly covers the costs of post-composting.

The “CDM” scenario keeps all the assumption from the baseline scenario but includes revenues from climate certificates. The revenues are assumed to be 10 US$/t CO2 eq.

The “Composting” scenario assumes that the plant is installed at an existing composting plant. The cost of the substrate and the sale of the compost are not included as it is assumed that these costs are attributed to the compost plant. Moreover, the office buildings, water and electricity supply are assumed to be existing. Also, the cost for work is lower due to efficiency gains. The other assumptions are as in the baseline case.

Table 5. Summary of financial indicators

	Baseline	**Low**	**High**	**CDM**	**Composting**
Invest Cost [US$]	47,080	47,080	47,080	47,080	43,480
O&M Cost [US$/year]	34,185	34,185	34,185	34,185	16,410
Revenue [US$/year]	10,253	5,029	48,390	25,309	7,543
NPV [US$]	-134,973	-154,161	5,091	-79,677	-76,046
LCE [US cents /year]	75	75	75	75	45
WTC [US$/ton]	96	110	-4	57	54

O&M: operation & maintenance; NPV: net present value; LCE: levelised cost of electricity; WTC: costs for treating one ton of waste

Table 5 summarizes the results of the financial analysis. Only the “High” scenario has a positive net present value. Generally, there is a large spread between the different scenarios. The profitability of a biogas project depends on many factors, which can vary greatly depending on the circumstances. For example, the future feed in tariff for electricity can vary between the current tariff of 8 cents/kWh up to a preferential feed in tariff of 35 cents/kWh. Additional to the uncertainty in cost and revenues, a new technology involves many operational uncertainties. Throughout the calculations it is assumed that gas is produced without major technological failures. The goal of the financial analysis is therefore not to give any definite numbers, but provide an idea how the financial analysis of such a project can vary and to give an idea which factors are important for profitable operation.

In summary it can be said that:

- The simple design of the dry fermentation plant leads to low investment cost. The high cost for the generator and grid connection are the same for any biogas technology.
- With regard to investment cost per cubic meter digester room, dry fermentation is comparable to wet fermentation.
- The choice of the site is critical. On the one hand the substrate costs are directly dependent on the site. They could be high in the case the waste needs to be transported over long distances and separated. They could even be negative, if the plant recycles the waste e.g. of a fruit factory which would otherwise have to pay a waste collection fee. On the other hand, the

revenues are again dependent on the site and on the local policies. The site determines which of the products can be used and in what way (heat, fertilizer, or electricity). The policy framework determines the market value to some extent.

- The overall viability is dependent on those revenue parameters as shown by the net present value results. A general conclusion whether dry fermentation is a financially viable technology is not possible. The technology can only be profitable within very favourable circumstances.
- Biogas from solid waste has a broad range of benefits from climate impacts to sanitation improvement and from renewable energy to agriculture. This makes the technology undisputedly attractive for a clean and sustainable development. On the downside, it makes the allocation of revenues and costs more difficult. This has in turn implication with regard to policy support, as it makes it unclear which ministry (energy, sanitation or agriculture) should be mandated to support the dissemination.

All figures and assumptions that were used for above calculations can be found in *Burri and Martius (2011)*.

3.4 Potential for GHG emission reductions / Opportunities for CDM

The potential for greenhouse gas (GHG) emission reductions of a full scale biogas plant has been calculated based on the characteristics of the pilot plant in Kumasi. Figure 3 shows the results of the calculations for the treatment of 301 tons per year of organic waste with a composition of 50% mixture of food and food waste and 50% garden, yard and park waste. The continuous lines show the emission reductions and the baseline emissions with respect to the years for which the calculation is made. The interrupted lines show the average of these quantities between the 1st and the 15th year. The baseline emissions are the amount of methane that would be emitted from the decay of the degradable organic carbon at a solid waste disposal site in the absence of the project. The average yearly emission reductions during the assumed project period of 15 years are 121.5 tCO2e/yr.

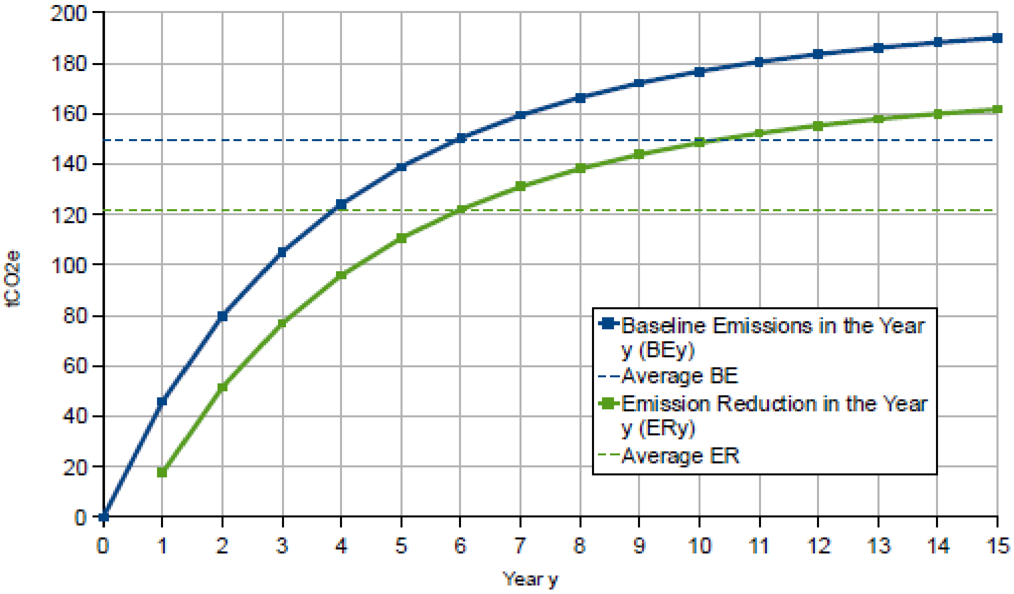

Figure 3. Results for the baseline emissions (in blue) and the emission reductions (in green). (Robbiani, 2011)

Based on the calculations above, different scenarios for implementing a CDM project were studied. As a baseline serves one single digester which treats 301 t/y composed of a mixture of food waste (50%) and garden, yard and park waste (50%).

Household waste: In this scenario, it is assumed that all the organic fraction of the waste coming from households of Kumasi is treated anaerobically through the implementation of a number of dry fermentation plants disseminated strategically throughout the city.

Market waste: In this scenario, it assumed that all the organic waste generated by the four main markets in Kumasi are treated anaerobically. The dry fermentation plants would be situated close to the markets.

Total mixed: In this scenario, all the organic waste of the city of Kumasi available for biogas production is treated anaerobically in dry fermentation plants. This would include waste from households, markets, industries and livestock.

Table 6. Summary of the results of the different scenarios

Scenario	Quantity of organic waste treated [tons/year]	CER earned on average over 15 years [CER/year]	Number of plants
Baseline	301	122	1
Households	64000	25800	213
Markets	60000	24200	199
Total (households, markets, industries and livestock)	128600	51900	427

The results above only give an indication of the potential emission reductions corresponding to such projects. The figures are based on assumptions and default conditions. The biggest assumption comes from the waste composition. It was assumed that all the waste that goes into the digesters is of organic nature, and composed of a mixture of food waste and garden, yard and park waste.

Another big assumption comes from the methane correction factor (MCF), which is determined according to the type of disposal site at which the waste would be deposited. A precise assessment of the site structure and the management practices of the site would have to be performed in order to have a more exact estimation of the MCF.

Other parameters such as the quantity of waste fed into the digester, the incremental distance for transportation of waste, physical leakage of methane, average truck capacity, and emission factor from fuel used due to transportation could also be measured on site taking into account the exact conditions of the specific project considered.

Furthermore, the grid emission factor (GEF) was taken from a study done in 2007. For a more accurate value of the GEF a calculation with the current situation would have to be performed. It should be pointed out that by implementing a CDM project with the total scenario in its full scale, where all organic waste available for biogas production of the city of Kumasi is considered, the yearly methane recovery would at some point exceed 60 ktCO2e, which is the limit above which the methodology for small-scale CDM-project activities is not anymore applicable, as prescribed by the CDM modalities and procedures. Although the average emission reductions over the first 15 years remains below 60 ktCO2e, this limit would be exceeded at the 9th year and onward.

Finally, attention should also be directed towards the number of plants that would have to be operated in each scenario. This number suggest that it might not be feasible to implement the scenarios at their full scale, because of the large space and monitoring issues such a project would require. Especially when considering the fact that each plant would be equipped with a composting station for the further treatment of residual material.

More details regarding GHG emission reductions and the different scenarios for implementing a CDM project are available in *Robbiani (2011).*

4. Impacts

The project is related to the REPIC activity *support of pilot and demonstration projects* and it is therefore difficult to show direct socio-economic impacts. The aim of the research project was to develop a new type of biogas digester which - once implemented on a larger scale - would contribute towards an improved waste management and the reduction of greenhouse gas emissions. However, at the present stage, it is still a research and demonstration project and not yet ready for implementation. Nonetheless, a lot of knowledge and experience related to dry fermentation was gained at the involved research institutes of KNUST, Eawag and ZHAW. But also the private company Zoomlion as well as actors from the public sector are now aware of this new treatment method although it is not yet ready for implementation. The project also contributed to knowledge transfer as several Swiss and local students have been involved in different tasks. A number of Ghanaian MSc students are showing interest in conducting their thesis related to the topic of dry digestion and we are confident that KNUST will continue research activities in this field. KNUST can also present itself as a ‘knowledge centre’ of this innovative biogas technology.

As a positive side-effect it can be mentioned that the project raised discussion about the valorisation potential of the organic fraction of municipal solid waste. Hopefully, more effort will be laid in future in recycling this important fraction.

As a very positive change it has to be mentioned that the pilot plant at KNUST shall be incorporated in the waste management plan of the University campus to treat all the organic waste originating from the student's canteens.

5. Future Prospects

On 24th of April 2012, key actors from research, private sector and local government were invited to participate at the stakeholder workshop that took place at KNUST in Kumasi. As the project also intended to explore how such a technology can be integrated into the municipal waste management system and be operated in an economically sustainable way, the stakeholders were invited to contribute in finding answers to these questions. The aim of this workshop was thus to disseminate the research results and to discuss the potential for implementation of the dry digestion technology in Ghana.

The Specific objectives of the workshop were

- To explain rationale behind the dry digestion project at KNUST
- To present the results of the research studies that have been conducted at KNUST, highlight experienced problems and examine further research topics
- To discuss the potential and constraints of dry digestion technology based on the study results
- To identify possible implementation strategies of the technology in the Ghanaian context with relevant stakeholders

It became clear throughout the workshop that the dry digestion technology is currently not yet sufficiently mature to be implemented by the public or private sector at a larger scale. Furthermore, the representatives of the Waste Department at KMA expressed their limitations in pushing the technology forward. Their priority clearly lays on working towards a SWM system which can cover its costs and further investments in new, unproven technologies cannot be considered at the moment. The academic sector, on the other side, showed substantial interest in this innovative technology and argued that further research is still needed before initiating the dissemination phase of the technology.

Partly as a result of the workshop, three Ghanaian MSc students (Environmental Resource Engineering) expressed their interest in writing their MSc thesis related to the dry digestion project under the supervision of Prof. Ebenezer Mensah. They wish to focus on the different post-treatment options of digestate, analyse its influence on crop yield and soil property, and look into the demand and possible use of this organic fertilizer. Dr. Moses Mensah offered to supervise two MSc students on writing their thesis related to the conception, design, implementation and operation of a dry digestion lab or (bench)-scale plant to better understand the dynamics within the digester. In addition, Dr. Mensah, as head of a KNUST-internal working group which is in charge of developing an Integrated Waste Management Plan for the KNUST campus, suggested to incorporate the dry digestion pilot plant in this waste management plan in order to formally include the plant in a KNUST scheme and thus clearly distribute the responsibilities for its operation and maintenance.

6. Conclusions

Batch dry fermentation plants have a simple design and low water and process energy consumption. They can use bulky solid waste as a substrate with a high dry matter content and the digestate can be easily post-composted. The construction of the pilot plant proved that the construction is possible to be realised in Ghana. It can be built at a low price with local material. On the basis of a shipping container a dry fermentation plant can be built without high-tech parts or specialized tools.

However, the pilot plant revealed some drawbacks of the technology: The airtight sealing remains a major challenge. Particularly the sealing of the door needs further investigation to find a permanent solution. The security risk of potentially explosive air/methane mixture is an important factor to consider. Methane is a burnable gas and explosive mixtures and sparks have to be avoided by all means. Operation is considerably safe if precautions are followed. In case of faulty handling however, severe accidents can occur. As the technology is not very mature yet, the security issue need further research, which includes the development of a digester room flushing system. Further research also needs to be directed on the durability of parts like the PVC piping or the sealed wooden floor. Although the plant construction is made with simple technology it needs to be operated and taken care of by trained personnel. If handled wrongly the delicate parts such as the sealing or the PVC pipe connections can be damaged easily. Because of the percolation system that has to be operated frequently, the operation of the plant needs regular attention and requires water and electricity.

Technology comparison to wet digestion

Comparing dry fermentation to simple wet fermentation technologies (such as Chinese fixed-dome digesters or floating-drum digesters) fewer arguments remain in favour of dry digestion. Wet digesters can also have a very simple design. No mixing or stirring device is involved, hence no electricity connection is needed. Performance and suitability is proven in a vast number of plants throughout Asia and Africa. The performance of the pilot dry fermentation plant however is yet to be proven. Nevertheless, the performance of dry fermentation plants in Europe show a competitive performance. Albeit there is a degree of uncertainty to the cost assessment, the economics show that the prices per digester volume are similar.

A striking advantages compared to wet fermentation is the suitability to ferment stackable substrate with high dry matter content and the handling of the digestate. This fact makes it a very suitable option to improve SWM. In a wet digestion process, municipal waste input has to be cut into small pieces by a shredder and is mixed with water. The subsequent digestate is liquid and cumbersome to handle. Currently over 90% of the biogas plants in Ghana discharge the effluent in public drains or bushes. This is associated with health concerns and environmental pollution. The effluent can contain pathogens and introduces large quantities of nutrients into water bodies. With dry fermentation the digestate is solid. It can be unloaded with shovels and forks. It can be easily piled up and post-composted. A simple shelter is sufficient to prevent leakage during heavy rains. Composting produces organic fertilizer and kills pathogens. This organic fertilizer can be transported with common trucks and applied to fields without specialized tools. If there is no demand for organic fertilizer, the compost can be dumped on the dumpsite without further treatment or health concerns.

Technology comparison to composting

Looking at dry fermentation mainly as a technology to treat organic waste, composting is another alternative. The technological advantages of dry fermentation are clear: The biogas production adds a valuable product while the post-composting of the digestate maintains all the advantages of only composting. Two main aspects have to be considered for the comparison of composting and dry fermentation. Firstly: It can be that biogas technology is too complex for developing countries. Secondly it might be too costly and a plant cannot be operated economically. Whether the technology is appropriate in respect of the ease of operation is too early to say. Many characteristics are very promising. With the current circumstances (energy prices, waste handling fees), dry fermentation is not financially viable. However, the financial problems are also true for any other biogas technology and hold true to some extent for composting, as the policies are unfavourable.

Framework Conditions

Ghana has no tradition in producing biogas. It only has about 100 biogas plants of which roughly half are in operation. Biogas plays a very marginal role in the energy sector. Other African countries have significantly wider dissemination of biogas plants, for instance Kenya about 2000 and Tanzania between 4000 and 5000.

SWOT Analysis

As a general overview on the project, the conclusions are summarized in a SWOT analysis.

Table 7. SWOT analysis as a general overview on the project

	Strengths	**Weaknesses**
Internal	- Low tech construction - Low investment cost - Easy handling of substrate and digestate - Low process energy needed	- Immature technology - Performance uncertainties due to lacking test - Durability uncertain - Technical problems unsolved (air tightness) - Security issues - Low market value of gas and compost
	Opportunities	**Threats**
External	- Improves SWM - Reduces GHG emissions - Closes nutrient cycles by producing fertilizer - Creates jobs - Reduces dependency on fossil fuels, wood fuels and energy imports - Renewable energy policies are being drafted	- Current, unfavourable conditions could persist - Impact of discovered oil reserves on renewable energies is uncertain - Trained personnel is rare - Acceptance of new technology is uncertain - Financial risks due to high discount rates

Recommendations

At this stage, several open questions remain regarding the reasons responsible for the low gas production. Therefore, it is necessary to know more about the gas potential and the suitability of the feedstock, but also if the container is really gas tight or if a substantial amount of gas is leaking. As the used gas meter was probably not suitable to measure the gas production, a reliable gas measurement device is necessary to ensure good measurement results.

In a next step, it is necessary to better understand the dynamics inside the container. With only one container and a retention time of 1-2 months, it is not possible to test and modify various parameters within a useful timeframe. It is therefore recommended to conduct batch tests with smaller bench-scale plants and to test different substrates, digestate/fresh feedstock ratios, retention times, and different modes of percolation.

With this information, it will then be possible to decide whether it makes sense to continue the project and to put more effort on optimising the digester.

Apart from the enhancement of the AD process, the post-treatment steps of the digestate and its quality compared to other organic fertilizer should be examined as well. Additionally, the improvement in soil characteristics and the changes in crop yield when applying post-treated digestate should be looked into.

Another important point to look into is to explore the market demand to find out the most promising form, distribution and use of the AD products (biogas and digestate).

7. References

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⇨ *Including a User Manual on how to operate dry fermentation plants (Appendix E)*

Robbiani, Z. (2011): Renewable Energy and Waste Management in Ghana. Potential for greenhouse gases emission reductions of a dry-fermentation pilot plant and opportunities for implementing a Clean Development Mechanism project. Semester project. Swiss Federal Institute of Aquatic Science and Technology (Eawag).

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Stakeholder Workshop Summary Report

Annex: Picture series

Picture 1. Solid waste dumpsite in Kumasi

Picture 2. Separation of organic waste

Picture 3. Delivery of feedstock by Zoomlion

Picture 4. Mixing of feedstock

Picture 5. Filled digester

Picture 6. Second, improved digester

Picture 7. Percolation system

Picture 8. Sealed doors

Picture 9. Pipe for percolate collection

Picture 10. Installation for gas measurements

Picture 11. Digestate after anaerobic treatment

Picture 12. Waste collection point at KNUST