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Subsector Analysis: Ghana

The biogas potential for anaerobic digestion of rice straw and husks, cocoa bean shells, and cashew nut shells in Ghana

Facilitator

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List of Abbreviations

AD = Anaerobic digestion
CFL = Compact fluorescent light bulb
CHP = Combined heat and power
CNSL = Corrosive cashew nut shell liquid
COD = Chemical oxygen demand
DM = Dry matter
FM = Fresh matter
GADCO = Global Agri-Development Company
K2O = Potassium
l = Liter
MIM = Mim Cashew and Agricultural Products Ltd.
MJ = Megajoule
NfE = Nitrogen-free extractives
NPK = Nitrogen, Phosphorous, Kalium (Potassium)
oDM = Organic dry matter
PLOT = PLOT Enterprise Ghana Limited
P2O5 = Phosphorus
WBT = Weihenstephan Biogas Potential

Executive Summary

Biogas, a sustainable renewable energy form, is at a starting point of market development in Ghana. Due to its economic growth and development of the regulatory environment, the Ghanaian renewable energy sector is attractive for foreign companies from the sector interested in investing in Sub-Saharan Africa. As a result of the present day energy situation, characterized by grid instabilities and increasing power prices, commercial and industrial producers from the agricultural industries look for alternative solutions to secure constant energy supply to avoid production loss and to reduce energy costs. The installation of biogas plants on production sites is one of the most attractive solutions. It enables producers to dispose agricultural waste, generate electricity for self-consumption, use residues as fertilizer and feed-in energetic surpluses to the grid at the same time.

The objective of the analysis is to provide companies and project developers with preliminary information on the potential for biogas within the Ghanaian rice, cashew and cocoa- processing sectors. All samples were taken in Ghana at 3 different farms which were selected due to their foodstock availability. The samples were subsequently analyzed in a European laboratory.

Rice:

- Substrates are very dry. There has to be a source of water for dilution. The theoretical demand of water is roughly 0.8 m³ per t FM to obtain wet slurry with 10% dry matter (DM), which is pumpable and digestible.
- Rice straw originates in the fields. Transportation of up to two hours driving for the straw has to be organized in addition to the rice grain transport. The low bulk density of straw needs to be taken into account when calculating the effort of transportation, storage and loading of the anaerobic digestion (AD) system.
- Rice husks are hard to degrade on-site. It has to be decided if co-digestion with the straw makes sense. There are also processing problems expected for the substrate rice husks, such as the effects of soaking or skimming.

Cashew:

- Cashew shells are taken to the processing plant and are hardly degradable in nature as well as in a biogas plant. They have to be utilized anyway.
- The effluent of a biogas plant has to be stored, treated and transported. This leads to further efforts and costs.
- The substrates are very dry and would need a large quantity of water to be processed in a digestion plant. Technologies that are specifically designed for this type of dry biomass, however, do exist.

Cocoa:

- The substrates are very dry but digestion is a wet process. There has to be a source of water for dilution. As mentioned, the waste water could be used. If this is not feasible, the theoretic demand of water is roughly 0.9 m³ per t fresh matter (FM) to obtain slurry with 10% DM, which is then pumpable and digestible. The actual water demand may vary from this estimate.
- The effluent of the AD plant has to be stored, treated and spread to the fields and/or transported. The latter requires special trucks. All these steps result in additional efforts and costs. For the successful implementation of the project, a thorough cost-benefit analysis has to be conducted.
- The effluent shows a certain quality as a fertilizer. Relevant characteristics are nitrogen, phosphorous, potassium and trace elements. The high-quality effluent will be usable for fertilization in order to increase the crops' yields – not only at cocoa plantations but also for other crops in PLOT´s vicinity.

The following sections provide an overview of the chemical structure of the feedstocks, their respective potential for anaerobic digestion and describe the energy situation of the respective sites and sectors.

1. Biomass resources and sampling

The materials analysed for the present study have been selected because they accrue during the food-processing. In most cases, these materials are burned directly at the site for process heat in simple open furnaces.
The two major residues of rice production are rice straw and husk. During harvesting season, rice straw is usually left as a residue on the fields. In the milling process, rice husks are the main by-products, often discarded as waste or burned on site. In comparison, the processing of cashews results in cashew nuts, cashew shells and for 1-2 months a year also in cashew apples. Once off the tree, cashew apples generally rot too quickly to be stored and processed. Although a few apples are used for the production of brandy, the majority remains as a residue on the fields.
Similar to that, the cocoa production creates pod husks, which remain as a residue on the cocoa plantation. Bean shells are another residue of the cocoa production. In the case of cocoa, there is a considerable amount of waste water involved in the processing. The table below shows the different residues based on one ton of fresh matter (FM) of rice, cashew and cocoa.

Table 1: Residues of rice, cashew and cocoa

1t each	**Rice paddy**	**Cashew nuts**	**Cocoa fruits**
Based on fresh matter	0.3t straw	0.7t shells	0.035t shells
	0.22t husks	Apples	0.7t pod husks

Source: GIZ

The rice samples were taken at Global Agri-Development Company GADCO: the straw from the fields and the husks from the dumping site. The dumping site is situated right next to the processing facilities, without a cover and on unpaved ground.
The cashew samples were taken at MIM Cashew and Agricultural Products Limited Company (MIM), situated in Sunyani, Brong-Ahafo region, approx. 120 km northwest of Kumasi. The cashew shells were taken from the production line. Waste water, due to its small amount, was not collected. Cashew apples were not in season during the period of taking samples. There is only a small amount of waste water (<10 %) produced throughout the year, but the amount rises to around 25% during the brandy production season.
Cocoa residue samples were taken at PLOT Enterprise Ghana Limited (PLOT), situated in Takoradi, approx. 200 km southwest from the capital Accra. Precisely, the bean shells were taken from the storage silo and the waste water from the ditch. Pod husks were not available.

1.1 The substrate analysis

The composition and characteristics of the substrates were analysed by means of chemical-technical analyses. To determine the feedstock´s suitability for anaerobic digestion (AD) purposes, batch tests were performed. Table 2 shows the chemical characteristics of the substrates whereas Table 3 presents the gas yields and results at a glance. Three graphs, representing the gas production over time, are found in the appendix.

Remarks on the analysis in Table 2:

- WEENDER: Quantitative method to determine fermentable substance in feedstock. Basically, it is the partition of feed compounds into ash, fat, fibre, protein/nitrogen and nitrogen-free extractives (NfE)
- Baserga: calculation of biogas yield and methane content
- Weihenstephan Biogas Potential Test (WBT®), according to Guidelines VDI RL 4630

Analysis and WBT® were performed at atres´ specialised biogas laboratory in Freising-Weihenstephan, under controlled laboratory conditions and according to standard methods.

Table 2: Chemical-technical analysis of rice straw and husks

	unit	Rice straw	Rice husks	Cashew shells	Cocoa shells
Dry matter (DM)	% FM	93,2	91,9	83,3	92,3
Water content	% FM	6,8	8,1	16,7	7,7
organic Dry Matter (oDM)[1]	% DM	89,3	79,5	98,4	91,6
Ash	g/kg DM	107	205	16	84,0
Nitrogen, total	% DM	0,84	< 0,5	0,83	2,9
Ammonia-Nitrogen (NH_4-N)	% DM	< 0,5	< 0,5	< 0,5	< 0,5
Phosphorus, total (P_2O_5)	% DM	0,36	0,06	0,15	0,86
Potassium, total (K_2O)	% DM	2,09	0,32	0,76	3,20
Crude protein	g/kg DM	71	28	53	165
Crude fibre	g/kg DM	229	476	197	151
Crude fat	g/kg DM	16	< 1	161	34,0
Nitrogen free Extractives (NfE)	g/kg DM	577	291	573	291
Chemical Oxygen Demand (COD)[2]	g/kg FM	863	875	1146	996
Ash content	% DM	-	21,71	1,60	9,43

Source: atres

Table 3: Gas yields and energy content – theoretic/calculated: figures of table 2; specific: results of WBT®

	unit	Rice straw	Rice husks	Cashew shells	Cocoa shells
Theoretic methane yield (COD)	l/kg FM	302	306	401	349
Theoretic methane yield (COD)	l/kg oDM	363	419	489	412
Theoretic biogas yield (Baserga)	l/kg FM	321	148	621	138
Theoretic biogas yield (Baserga)	l/kg oDM	385	203	714	189
Theoretic methane yield (Baserga)	l/kg FM	173	78	360	73,1
Theoretic methane yield (Baserga)	l/kg oDM	208	107	416	100
Theoretic methane content (Baserga)	vol.-%	54	53	58	53
Specific biogas yield (WBT®)	l/kg FM	313	29	n.b.	353
Specific biogas yield (WBT®)	l/kg oDM	401	41	n.b.	415
Specific methane yield (WBT®)	l/kg FM	171	18	n.b.	193
Specific methane yield (WBT®)	l/kg oDM	219	26	n.b.	227
Specific methane content (WBT®)	vol.-%	54,7	61,7	n.b.	54,7
Gross energy content, calculated	kWh/kg FM	1,7	0,2	3,59	1,92
Gross energy content, calculated	MJ/kg FM	6,1	0,6	12,89	6,91
Gross calorific value, caloric analysis	MJ/kg FM	-	14,1	16,41	16,6
Net calorific value, caloric analysis	MJ/kg FM	-	12,9	17,97	15,3

Source: atres

1.2 Discussion of the results

The figures in Table 3 represent a first estimation of the potential of biogas production out of the different substrates listed above. It should be noted that the samples were only taken at one site. Differences between theoretic and specific figures relate to the analytical setup and the respective methods. Figures are always compared with specific numbers, calculated to the reference of organic dry matter (oDM).

In general, specific methane yields depend on the calculation method. The decrease of methane yields is highest with the COD (chemical oxygen demand) method, less with the Baserga method and lowest when using the WBT® method.

The specific methane yield has been calculated by using the fixed relation of 350 l methane being produced per 1 kg of COD. The calculation via COD is equivalent to the maximum methane yield. It is based on the theoretical assumption that every compound is able to be oxidized. However, in practice different results can be observed. The COD method is a very strong and chemical cracking method, which does not differentiate between hard and soft degradable compounds.

The Baserga calculation is based on numbers of the WEENDER chemical analysis, using the average animals' digesting parameter. In contrast to these chemical and combined chemical/biological methods the strictly microbial based WBT® method gives a more realistic approach. Microbial availability and degradability of the feedstock is more relevant than absolute figures of single chemical compounds since only bioavailable compounds can be used in the process.

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[1] oDM – organic dry matter

[2] COD – chemical oxygen demand

1.2.1 Rice

The abovementioned differences between the COD, Baserga and WBT® method become visible through the values from rice husk: The COD calculation results in 419 l, Baserga in 208 l and WBT® in 25 l – all values in l methane per kg oDM. The decrease of these numbers is related to the husks´ composition.
The results for straw are quite similar to the ones for husk: a COD calculation results in 362 l, Baserga in 219 l and WBT® in 171 l – again all of them in l methane per kg oDM.
It can be seen that the differences between the results are smaller than those of the husks. This is due to the better microbial availability and degradability of the straws` composition.
Rice husks show a strong and hardly degradable structure since it is based on hemicellulose and lignin. The fibre content is twice as high as the fibre content of straw, yet the Nitrogen free extractives (NfE) of husks are half of the straw´s content. Husks do not show any crude fat and only half of straw´s crude protein.

The ratio between the specific methane yields of COD and WBT® gives an estimation of the substrate´s degradability under anaerobic conditions:

- Degradability of straw: 60 %
- Degradability of husks: 6%

Both straws and husks show similar theoretical gas potentials by using the COD method. Differences in relation to WEENDER and Baserga calculations are based on the analytical methods. Differences to microbial WBT® relate to the more easily degradable substances of straw on the one side, and on the poor gas yield of husks due to their poorly degradable layers on the other side.

1.2.2 Cashew

Large differences can be seen in the specific gas yields of WBT®, where no biogas production could be found through the chemical analysis of the substrate.
Cashew shows a high content of strong and hardly degradable structure, such as compounds based on hemicelluloses, lignin and crude fibre.
Additionally, the cashew shells contain certain substances that lead to a reduced activity of methane producing microorganisms. When analysing only the easily degraded fraction, cashew also contains NfEs, which are high in content. Protein and fat content are measured in a medium range. In a first conclusion, this means that cashew shells show a very low yield of methane through the microbial method WBT®, based on hardly degradable compounds as well as microbiological inhibitors.

1.2.3 Cocoa

Cocoa waste water will not be further analysed in this report due to the poor content of suspended and dissolved solids. Cocoa bean shells show a low content of strong and hardly degradable structure. These include compounds based on hemicelluloses and lignin or crude fiber. NfE are high in content and among to the fraction which is being degraded relatively easily. Protein and fat content are also in an interesting range.
The results are a higher specific biogas yield than expected. The COD validates the specific gas potential of bean shells with the relation of 350 l methane being produced per 1 kg of COD degraded. To sum up, cocoa bean shells show a very interesting yield of methane by microbial method WBT®, due to easily degradable compounds. Differences with in the WEENDER and Baserga calculations are based on the analytical approach.

1.2.4 Suitability for the generation of energy

All substrates have in common that they are very dry. Therefore, combusting seems to be the most feasible way of energetic utilization. In the case of rice husks and cocoa shells, this is already being done. Most of the combustion systems are however simple furnaces, with manual loading and direct combustion, which results in inefficiency and a low quality of flue gas. But it also implies low investment rates and low operational costs which in turn is very attractive for potential investors.

Both the straw and the husks show a high content of dry matter and respectively less than 10% water. On average, each kg of rice straw has a calorific value of 2,400 kcal/kg and is equivalent to 10 MJ (2.8 kWh) of gross energy content; whereas each kg of rice husks has a calorific value of about 3,000 kcal/kg and is equivalent to 12.5 MJ (3.5 kWh) gross energy content [Zafar].
Cashew shells show a high content of DM, with less than 17% water. On average, each ton of cashew shells (FM) has a calorific value of 3.59 kWh/kg, only 11% less than hard wood with the same water content (4.03 kWh/kg) [LWF].
Cocoa bean shells show less than 10% water content and a high content of DM. On average each kg of bean shells has a calorific value of 4,500 kcal/kg, which is equivalent to 19 MJ (6.4 kWh) [Marcel et al.]. All mass properties are related to FM. These results suggest that the solution of combustion seems to be the most promising.

The substrates indicate a certain potential of producing biogas by means of AD. On average, each kg of rice straw produces approximately 170 l methane, equivalent to 6.1 MJ (1.7 kWh) gross energy content, while each kg of rice husks produces approximately 18 l methane, equivalent to 0.6 MJ (0.2 kWh) gross energy content. The literature presents similar figures for digesting rice husks: 13.90 l [CUNDR and HALADOVA] and 12 l [OFOEFULE et al.], all in l methane per kg oDM. In 1995 the biogas yield was recorded by [EZE], with 18.37 l biogas per kg DM.
Cashew nut shells do not offer any methane production when used singularly in the process, due to the corrosive cashew nut shell liquid (CNSL). This liquid is located in between the two skins of the cashew nut. This aggressive, corrosive CNSL is, extracted and purified, used as an insect repellent in some areas [Akpotu; Farias et al.]. Active substances of CNSL are inactivated during the roasting process of the nuts.
As mentioned above, cashew apples were not available for sampling at the MIM cashew plantation. Although they are a big part of the harvesting process, the role of the apple is very small. MIM produces brandy out of cashew apples for only a few weeks of the year.

Apart from the brandy production season, there is only a small resulting amount of process waste water in the processing of cashew nuts. Because of this short period and in addition to the very weak storage property of the fresh apples, the utilisation of the cashew apples is not taken into account for further calculations.
The fresh matter each kg of cocoa bean shells, on the other hand produces approx. 193 l methane, which is equivalent to 6.9 MJ (1.9 kWh) gross energy content.
To put this energy value into perspective, less than 2 kg of rice husks can produce 1 kWh of electricity, enough to power a 26-watt compact fluorescent light bulbs (CFL) for nearly 40 hours [GE Report]. The same energy can be generated out of less than 1 kg of cocoa bean shells [RICO et al.].

2. The situation at GADCO (rice)

2.1 Background GADCO

Figure 1: GADCO´s site view – husk storage (left), production facilities (right), piping for transportation of husks.

Source: GIZ Image

GADCO (Global Agri-Development Company) operates a modern hub farm in Ghana, with an initial focus on rice production, and a program that leverages the resources and infrastructure of the hub farm to provide smallholder farmers with critical production services, inputs (including high-yield seeds) and access to end consumer markets in high-growth food categories.
The company uses its command of the full value chain to process finished products for the domestic market through their own brand, Copa. GADCO is currently selling its Copa Jasmine rice, and will launch derivative products with an emphasis on meeting local

market preferences, and affordability through marketing and distributing to base of the pyramid focused consumer markets.[3] In total 1,200 ha of land are owned by GADCO.

2.2 Biogas/Energy potential at GADCO

The basic intention of an AD plant at GADCO is to utilize the rice husks on-site and to supply the production lines with both thermal and electric energy.
Calculating the biogas yield at GADCO by using only rice husks would result in 1,800 m³ methane per month, equivalent to 1,800 l diesel fuel. Converting the fuel into electricity using a CHP results in 10 kW_{el} and 11 kW_{th}, assuming an electric efficiency of 38% and 8,760 operational hours per year. This output seems to be very poor, especially when taking into account the effort for producing biogas. However, the output is likely to increase by the additional use of rice straw. Using only rice straw, the potential increases significantly: 340,000 m³ methane per month, equivalent to 345,000 l of diesel fuel, respectively a biogas-fired combined heat and power (CHP) with a power of 1.8 MW_{el} and 2.1 MW_{th} (assuming the same efficiency).

2.3 GADCO´s demand for energy

Some basic figures on GADCO´s current situation are depicted in Table 4. Special facts and figures are described in the following passages.

Table 4: Fact sheet GADCO Ghana Ltd.

	unit	amount
Rice husks	t/month	100
Rice straw	t/month	2000
Electric energy demand	kWh/month	20,000
Electric energy demand, costs	USD/month	5,500
Average electric power demand	kW_{el}	500
Diesel demand only for mill	l/month	6,000
Diesel, costs	USD/l	0,78
Diesel demand, only for the mill, costs	USD/month	4,680
Transportation costs, own truck	USD/t	5,25

Source: GIZ survey

2.4 Opportunities for energy production

The processing of rice paddies demands thermal and electric energy. Thermal energy is utilized for drying the rice paddies; the process of drying for each batch takes 8 hours and treats 20 t of rice. Thermal energy is provided by combusting rice husks in a simple furnace. The burning takes place without any pre-treatment, such as compressing or briquetting. A fan then transports the hot flue gas through the drying facilities.

Electric energy is used for operating the fan at the combusting and drying facility, operating the sorting and milling facilities and supplying the estate with light. The administrative building is not located at the mill but approx. 5 km away from it – meaning that there is no additional demand for electricity for light and air conditioning on-site. For the administrative building, electric energy is provided by the grid or a backup set of generators.
The generators are being operated with diesel, with an average consumption of 200 l per day.

[3] Self presentation: http://acumen.org/investment/gadco-cooperatief/ (access 21/3/2017)

In the case of a blackout of the electric grid, GADCO faces a second problem: the rice will be charred due to an insufficient and uncontrolled drying process.

The blackouts and costs related to the backup system, as well as the interruption of production, raised interest in the use of a combined heat and power unit (CHP) with biogas.

GADCO has a good relationship with the community of Sogakope. The community has its own interest in overcoming blackouts and is, therefore, eager to participate in the production of electric energy with biogas.

This fact sheet is based on data collected at GADCO Ghana Limited and samples were taken only once. The here presented figures represent a basic approach for developing a tailor-made, individual concept and reliable solution for the customer.
However, various conceptual, technical and economic differences between the single AD systems and plants exist.
The study focused on the biogas potential of different food stock, but not on developing project or conducting feasibility studies
Though the biogas potential is quite interesting at a first glance, further questions and facts have to be taken into account if a concret project will be designed:

- Substrates are very dry. There has to be a source of water for dilution. The theoretical demand of water is roughly 0.8 m³ per t FM to obtain wet slurry with 10% DM, which is pumpable and digestible.
- Rice straw originates in the fields. Transportation of up to 2 hours driving for the straw has to be organized in addition to the rice grain transport. The low bulk density of straw needs to be taken into account when calculating the effort of transportation, storage and loading of the AD system.
- GADCO does not produce the rice on its own but cooperates with 600-900 local farmers. Therefore, availability and logistics have to be taken into account if the concept for a biomass and fertilizer project is designed.
- Rice husks are hard to degrade on-site. It has to be decided if co-digestion with the straw makes sense. There are also processing problems expected for the substrate rice husks, such as the effects of soaking or skimming.
- The effluent has to be stored, treated, spread to the fields and/or transported. Transportation requires special trucks, which results in extra efforts and costs that make the benefits questionable.
- The effluent is suitable for basic dilution and mashing of the input substrate – but more interesting is its quality as a fertilizer. All relevant characteristics are present: nitrogen, phosphorous, potassium and trace elements. It might be used to increase the crops' yields. Another positive effect is the upgrading/reusing of water for diluting/mashing of the AD plants' feedstock.
- The company owns 60-100 ha of unused land in the vicinity of the rice mill. It might be advantageous to grow additional biomass such as special grasses. Expected positive side effects would be increased biogas yield, optimised economies of scale, less required transportation as well as possible positive social impact of employment and income on-site. Crops like maize should be utilized as food or preferably as feedstock, of which only the by-products being used for the production of biogas.
- Biomass has to be validated, in amount and availability throughout the year to determine the demand for storage or alternative sources. Rice straw only arises during harvesting season.
- Ghana´s growing seasons offer the opportunity to harvest alternative crops during the whole year – this would result in less required storage space and continuous availability of feedstock.
- Right next to the rice mill there would be enough space for building an AD plant as well as storage or treatment facilities.

An additional option for stabilizing the economic reliability of an AD plant will be GADCO´s plans to double its production, due to the installation of a second line for milling. The current 3,000 t per year will increase to up to 6,000 t per year within the next 3 to 5 years. At the same time, the amount of substrates for producing biogas will increase – covering the simultaneously increasing demand for energy used for production.

3. The situation at MIM (cashew)

3.1 Background MIM

MIM Cashew (Mim Cashew and Agricultural Products Ltd.) is a family owned cashew plantation and processing facility, located near the rocky outcrops of the Mim mountains in Ghana.

MIM sees a wealth of potential in Ghana. The climate is ideal for growing different kinds of food crops, and many Ghanaians are both capable and available for good, secure and stable jobs. MIM believes that it is possible to produce good quality products in Ghana and to develop value adding activities for the benefit of Ghanaians and for the country as a whole.[4]
MIMs objectives are:

- To make the best quality cashew kernels in the world, all produced and packed locally in Ghana
- To add value to Ghanaian raw materials within Ghana itself
- To increase exports and professionalism of the cashew sector
- To develop attractive employment in a rural environment under sustainable production practices
- To provide sustainable and attractive job opportunities for women in the local rural environment, while respecting local family structures and traditions to stay intact
- To generally contribute to Ghana's positive development

3.2 Biogas potential at MIM

The processing plant is connected to a new grid substation so the power supply for MIM is relatively reliable – compared to other regions in Ghana and the other companies analysed in this subsector analysis. Despite that, ongoing blackouts and costs related to the backup system have led to the analysis of operating a CHP with biogas. Additionally, a very high energy consumption leads to energy costs of around 15,000 – 20,000 USD per month. Using the waste of the production processes may reduce the costs for the energy supply and help to make the company more competitive.

There is no biogas production possible when using only nut shells in an AD plant because of the microbiological inhibition substances. Even if there is a possibility to get rid of the inhibitors, the ongoing problem is that cashew shells are hardly degradable, due to the high content of lignin and lignocellulose.
Taking into account the calorific values of the cashew shells, there are better technologies available (for example biomass gasification, burning, co-firing in biomass or coal based power plants) to utilize and get rid of this waste stream.
In former internal research of atres, the second waste stream, cashew apples, showed a biogas potential of about 24 m³ methane per ton substrate FM, or 290 m³ methane/ton oDM. With an amount of 1,000 t of FM with a typical content of organic DM of about 8 %, it is possible to produce biogas with a calorific value of 240 MWh. With this calorific value it is possible to run a CHP with about 10 kW if enough space for storage is provided.

3.3 MIM's demand for energy

Some basic figures on MIM's actual situation are depicted in Table 5. The processing with the respective energy requirement is described in the following section.

The processing of cashew nuts demands thermal and electric energy as well as pressured air, which in turn is produced by an electrical compressor. For the majority of processing stages, electrical energy is needed, while thermal energy is required only for producing steam and hot air. Steam is mainly produced by burning shells, wood and other fuels. The steam helps with the peeling of the nuts and also serves to get rid of the acidic liquid between shell and nut. The hot air is needed for drying the nuts after peeling and sorting.
Once dried, the nuts are treated with steam for a thermal shock and dried again afterwards. After another sorting process, the nuts are heated up again to be disinfected, in the so-called "killing step". Finally they get cooled and packed for export.

[4] Self presentation: http://www.mimcashew.com/Our-Objectives.3.aspx (access 21/3/2017)

Table 5: Fact sheet MIM Cashew & Agricultural Products Ltd..

	unit	amount
Cashew shells	t/month	425
Cashew apples* (*only January – March)	t (FM)	1,000
Cashew apples* (*only January – March)	t (pressed)	600 - 800
Electric energy demand, costs	USD/month	15,000 – 20,000
Average electric power demand	kW_{el}	500
Diesel demand	l/month	10,000
Diesel costs	USD/l	0,78
Diesel costs	USD/month	7,800

Source: GIZ survey

3.4 Opportunities for energy production

Though the energetic potential is quite interesting at a first glance, further questions and facts have to be analysed in detail:

- Cashew shells are taken to the processing plant and are hardly degradable in nature as well as in a biogas plant. They have to be utilized anyway.
- Additional substrates for dilution of the inhibition substances are not available – there are no known additional waste streams around the processing plant.
- The effluent of a biogas plant has to be stored, treated and transported. This leads to further efforts and costs.
- The effluent will have a certain quality as a fertilizer, namely NPK and some trace elements, which can be used to raise future production on the field and also to reduce the amount of necessary, externally bought fertilizer.
- The substrates are very dry and would need a large quantity of water to be processed in a digestion plant. Technologies that are specifically designed for this type of dry biomass, however, do exist.
- Biomass has to be validated, in amount and availability throughout the year, to determine the demand of storage or alternative sources.

The benefits of a company-owned energy production – besides the savings in payments to the grid operator - are influenced by a variety of factors, as mentioned above. The overall balance between the company's energy demand and the potential of energy-production facilities on-site has to be calculated thoroughly – depending on the final concept and technical solution.

4. The situation at PLOT (cocoa)

4.1 Background

PLOT Enterprise (GH) Ltd is a Cocoa Processor based in Takoradi, in the Western Region of Ghana, the region where about 60% of Ghana's cocoa is produced and close to the Commodity village, the biggest CMC takeover point. The close location to the Takoradi port provides an excellent infrastructure for worldwide shipping with regular service to most destinations. The company has put up a factory in the highest cocoa producing area of western Ghana to process cocoa beans into cocoa butter and cocoa powder.[5]

4.2 Biogas potential at PLOT

Similar to the other two sites, the use of a CHP biogas plant for the company's supply of heat and power was analysed for PLOT. Using only bean shells, the biogas yield would result in 386,000 m³ of methane per month, equivalent to 390,000 l diesel fuel.

[5] Self presentation: http://www.plotghana.com/ (access: 21/3/2017)

Converting the fuel into electricity by a CHP plant would result into 2,000 $kWh_{el.}$ and 2,400 kWh_{th}, assuming an electric efficiency of 38% and 8,760 operational hours per year.

The waste water was not in the focus of this analysis due to its low biogas potential and small amounts of only a few m³ per hour. Nevertheless, the waste water is an interesting part of PLOT´s potential: If being discharged to surface water, the waste water would have to be treated somehow beforehand. However, the waste water may be used for dilution purposes: the bean shells have to be diluted/mashed to produce a pumpable/digestible mash of 9 to 12 % DM. Waste water would be the best solution since there are no extra costs involved and no additional demand of dwell water.

An AD plant will be able to combine the treatment of these two residues within one facility: cost effective and technically reliable.

4.3 PLOT´s demand for energy

Some basic figures on PLOT´s actual situation are depicted in Table 6. The most notable facts and figures are presented in the following section.

The processing of cocoa beans demands thermal and electric energy. Thermal energy is utilized for the drying and roasting of the cocoa beans. Currently, thermal energy is provided by combusting bean shells or diesel. A simple furnace is used for combusting bean shells, without any pretreatment such as compressing or briquetting. The bean shell furnace produces 4 t/h steam. A diesel fired burner provides additional thermal energy, producing 6 t/h of steam. The steam production works without metering and relies only on the perception of the maintenance staff.

PLOT has installed a diesel generator with 1.100 kW to provide electrical energy whenever it is needed. Currently, this is at least a few hours a day. Without the diesel generator as a back-up, blackouts would cause huge financial losses of 70,000 – 100,000 USD per month, the management estimates. A reliable energy production, based on the company’s waste, could obviously be an interesting possibility to save money as well as to get rid of waste products.

Table 6: Fact sheet GADCO Ghana Ltd.

	unit	amount
Cocoa bean shells	t/month	200
Electric energy demand	kWh/month	-
Electric energy demand, costs	USD/month	27,000
Peak electric power demand	kW_{el}	1,100
Diesel demand	l/month	90,000
Diesel costs	USD/l	0,70
Diesel demand, costs	USD/month	63,000
Costs for energy demand	USD/month	27,000

Source: GIZ survey

4.4 Opportunities for energy production

Though the biogas potential is quite interesting at a first glance, further questions and facts have to be taken into account:

- PLOT buys the cocoa beans from the Ghanaian cocoa board. The Ghanaian cocoa board is also responsible for the transportation to PLOT. There is no direct contact to the farmers. Therefore, availability and logistics have to be taken into account if the concept for the biomass’ and fertilizer project is designed.
- Cocoa husks offer an additional biogas potential. However, husks originate at the plantation during the harvesting of the fruits, thus the transportation of the husks would have to be organized in addition to that of the cocoa beans.

- Cocoa husks are used as fertilizers. After the use of the cacao husk in the AD plant, the digestate has to be returned. This demands further transportation and logistics.
- The cocoa plantations are not in the vicinity of PLOT but at least 1-6 hours car drive away. This has to be taken into account when calculating the effort and cost of transportation.
- The substrates are very dry but digestion is a wet process. There has to be a source of water for dilution. As mentioned, the waste water could be used. If this is not feasible, the theoretic demand of water is roughly 0.9 m^3 per t FM to obtain slurry with 10% DM, which is then pumpable and digestible. The actual water demand may vary from this estimate.
- An additional benefit of using the waste water in the AD plant is the reduction of effort and costs for the water treatment.
- The effluent of the AD plant has to be stored, treated and spread to the fields and/or transported. The latter requires special trucks. All these steps result in additional efforts and costs. For the successful implementation of the project, a thorough cost-benefit analysis has to be conducted.
- The effluent shows a certain quality as a fertilizer. Relevant characteristics are nitrogen, phosphorous, potassium and trace elements. The high-quality effluent will be usable for fertilization in order to increase the crops' yields – not only at cocoa plantations but also for other crops in PLOT´s vicinity.
- Cocoa husks only accrue during harvesting season. The demand on storage and conservation for a continuous use in the AD plant has to be evaluated.
- Since the public grid is not very reliable, the declared long-term target of PLOT is to constantly raise the amount of company-owned renewable energy for the production processes in order to increase their energy autonomy. This manifests itself in a very strong interest in the implementation of RE projects.

5. Conclusions

In general, the biogas potential in Ghana is clearly bound to the agro-industry and its future development.

It might be summarized as below:

- Ghana´s growing seasons offer the opportunity to harvest alternative crops during the whole year – this would result in less required storage space and continuous availability of feedstock. However, biomass has to be validated, in amount and availability throughout the year to determine the demand for storage or alternative sources. Rice straw and cocoa for instance only arise during harvesting season.
- Many agro-businesses do not produce rice, cashews and cocoa on their own but cooperate with 600 – 900 local farmers. Therefore, availability and logistics have to be taken into account if the concept for a biomass and fertilizer project is designed.
- The effluent of biogas has to be stored, treated, spread to the fields and/or transported. Transportation requires special trucks, which results in extra efforts and costs that make the benefits questionable.
- Cashew shells are taken to the processing plant and are hardly degradable in nature as well as in a biogas plant. They have to be utilized anyway. The substrates are very dry and would need a large quantity of water to be processed in a digestion plant. Technologies that are specifically designed for this type of dry biomass, however, do exist.

Generally, it is recommended to establish cooperation with local partners who can assist in overcoming the country specific conditions, laws and even cultural barriers. In the long term, the merger with a company that has been on the market for some time, could be a more effective solution than the establishment of an own subsidiary and the confrontation with all the peculiarities of the Ghanaian market.

In the end, there is one major issue that will positively affect the promotion of biogas projects: the acceptance of renewable energy systems largely depend on long-term successful projects. The present attitude towards biogas is positive, but can become negative if such biogas systems are neglected and not followed-up with maintenance activities which don't show profitability because of bad business concept behind them.

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Appendix A – Gas formation curves

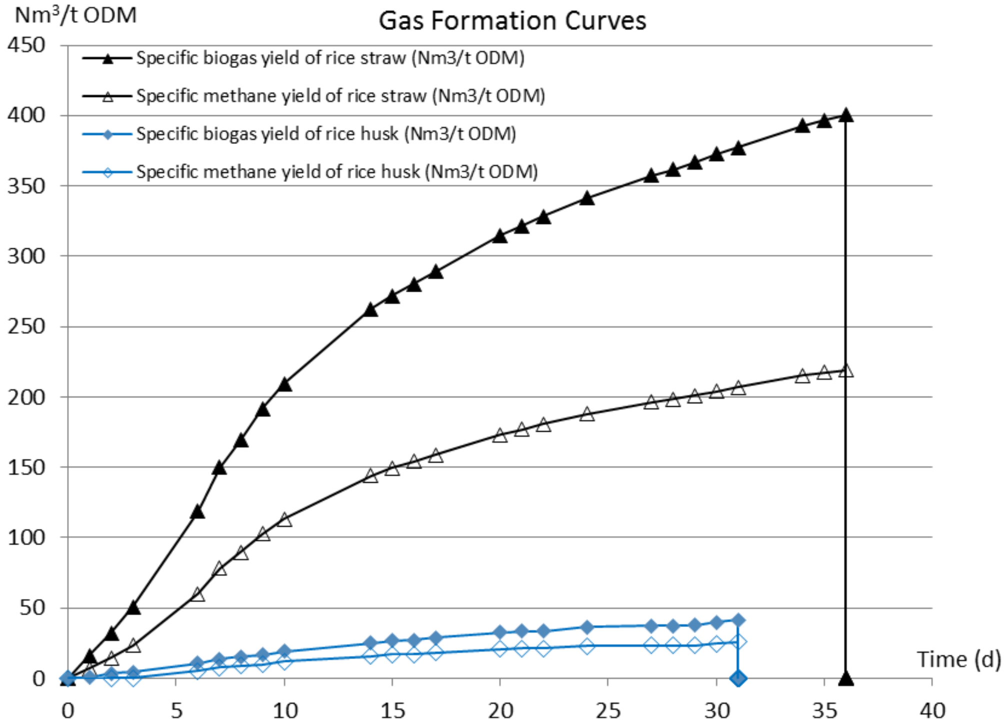

Figure 2 - Biogas and methane potential of rice straw and husks, temperature at 39 °C,

Source: GIZ

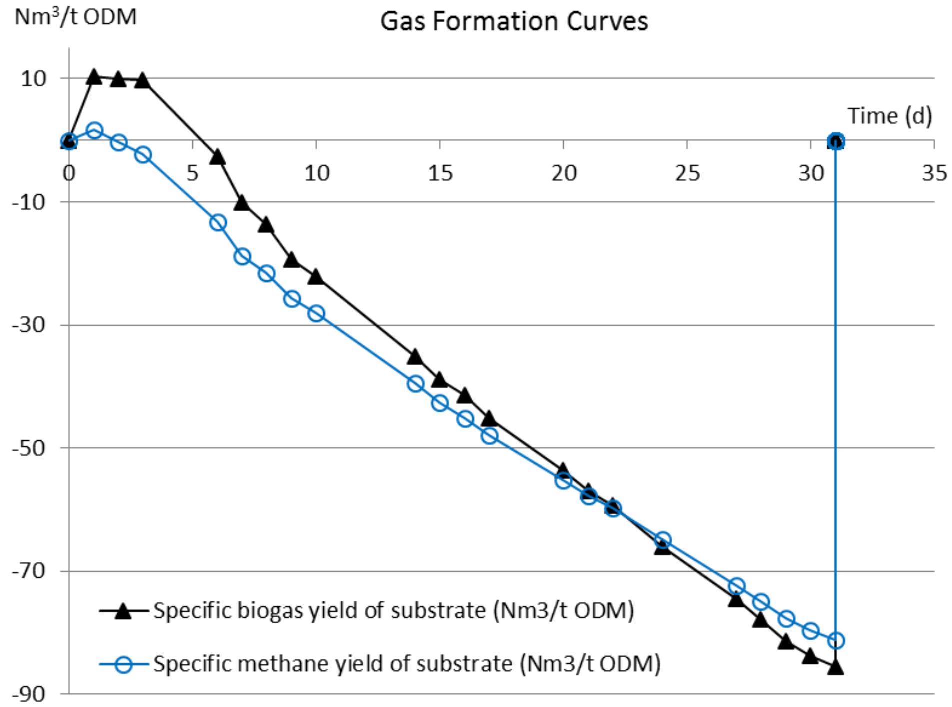

Figure 3 - Biogas and methane potential of cashew nut shells, temperature at 39 °C

Source: GIZ

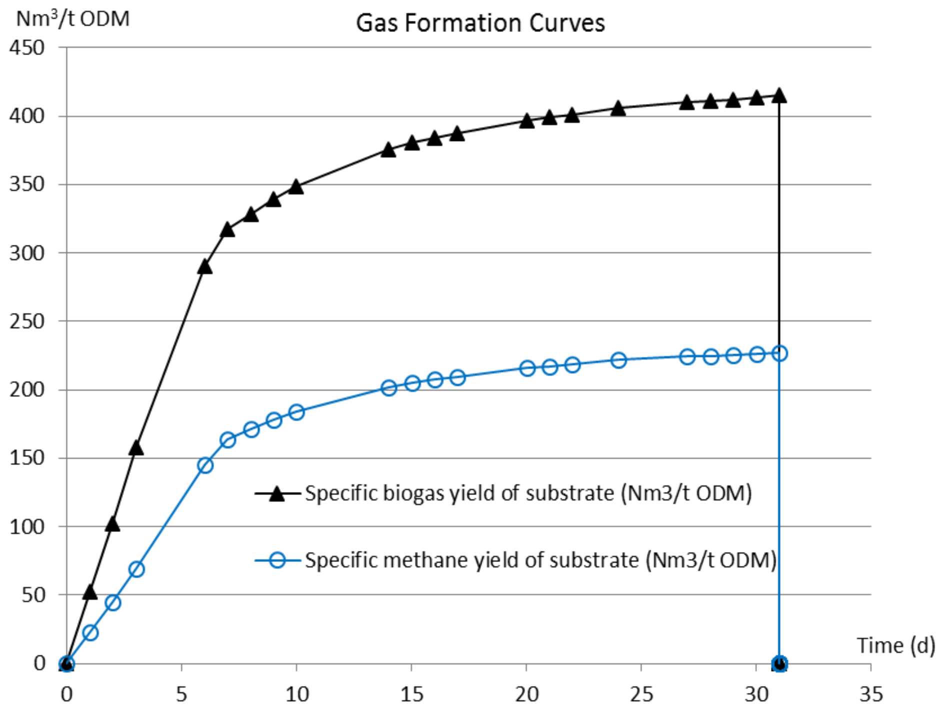

Figure 4 - Biogas and methane potential of cocoa shells, temperature at 39 °C,

Source: GIZ

www.german-energy-solutions.de/en

www.bmwi.de