Analysis of Family-Farm-Based (FFB) and Pig-Fattening-Based (PFB) biogas production in Brazil and optimisation potentials

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Abstract

Brazil is one of the biggest producers of animal protein worldwide. This is connected with a considerable livestock population and a huge production of manure. The use of manure in biogas plants has several advantages such as preventing direct methane emissions from lagoon-type storage systems, while using the biogas for electricity and/or heat production. After the fermentation process, the digestate can be used as high-value fertilizer. Two concepts of biogas production in Brazil are examined and compared to European biogas plants with deduced optimisation potentials and barrier analysis for the implementation.

Introduction

This paper is an outcome from the collective effort of (i) the University of Natural Resources and Life Sciences of Vienna (BOKU), which led the research; (ii) Eletrobras and ITAIPU Binacional in Brazil, which provided the concept of producing and using biogas as an renewable energy product and made available all support needed to conduct on-site and real scale research; and (iii) the United Nations Industrial Development Organization (UNIDO), which coordinated the project together with BOKU.

Brazil’s energy matrix is based on nearly 90% renewable energies, with nearly 82% hydroelectric power. Other renewable energies became more important in the last years. Generally speaking, biogas can play a crucial role, not only in securing energy supply, but also in mitigating climate change as well as creating development opportunities in the rural areas. Biogas additionally presents flexibility and multiple applications. It can be used to fuel engines and boilers, and the waste heat from these machines canprovide heating and hot water. In addition, the digestate is a high-quality, nitrogen-rich fertilizer for urban farming or local agriculture[1], [2].

The research work is based on the analysis of the two different biogas production concepts Family-Farm-Based (FFB) and Pig-Fattening-Based (PFB). The objective of this work is a technical, economic and ecological situation analysis on three representative farms in FFB and one in PFB to facilitate the installation and to enhance the efficiency of future biogas plants. Due to this, optimisation potentials as well as barriers for the implementation of biogas plants in Brazil are shown. Most of the needed technical, economic and ecological parameters have been determined during three months of stay in Brazil. Some were provided by ITAIPU or respectively by surveys of the four facility managers.

M**aterial and Methods**

Field experiment

The examined Biogas plants are situated in the region Basin Parana III, Parana, Brazil.

The FFB biogas plants are located near Marechal Cândido Rondon, where a Micro-Biogas-Grid was build up to connect 33 small scale biogas plants to a CCP at the micro-central point. The biogas is produced in Clean-Development-Mechanism (CDM) fermenter implemented in the Canadian architecture for pig fattening farms. At dairy cow or mixed farms Bio-Köhler (BK) fermenters are installed. The produced biogas is stored temporarily and after compression fed into the Micro-Biogas-Grid. At the micro-central point the raw-biogas is stored and purified. Due to the purification facility, the biogas can theoretically be used as fuel. For this paper three representative farms out of the 33 were chosen. One dairy cow, one pig fattening, and one farm with combined livestock have been examined.

The PFB biogas plant is located near São Miguel do Iguaçu on a pig fattening farm. The production of biogas takes place in a CDM-fermenter also built in the Canadian architecture. The gas is used on-farm to produce electricity for self-supply and for feeding into the electric-grid of Brazil.

Table 1 gives an overview of the examined biogas plants referring to the farm concept, the livestock, the fermenter and the gas usage.

Table 1: Overview of the examined biogas plants

	Farm-Concept	Livestock		Fermenter	Gas-Usage
		Swine	Cattle		
A	FFB	5	11	BK	Central
B	FFB	27	23	BK	Central
C	FFB	1024	2	CDM	Central
D	PFB	4800	---	CDM	On-Farm

The technical situation analysis is based on the VDI guideline 4631 – Quality criteria for biogas plants. Parameters and key figures for the examined biogas plants were deduced and some have been added. The used and the calculated parameters are shown in Table 2.

Table 2: Measured parameters for technical situation analysis

Measured parameters	
Substrate:	The *Volatile Solids (VS)* have been analysed referring to DIN EN 12880 (550°C) The *Daily Load* has been measured using measuring cups.
Fermenter:	The *Usable Fermenter Volume* has been measured using a standard measuring tape for The PFB, CDM fermenter The *gas compositions* were measured using Dräger / Monitor X-am 7000
Gas treatment:	The *Degree of Desulfurization* was measured using Dräger / Monitor X-am 7000 in front of and after the installed desulfurization facility
Calculated parameters	
Fermenter:	The *Hydraulic Retention Time*, the *Loading Rate*, the *Degree of Degradation* and the *Methane Yield* were calculated based on VDI 4631
Entire complex:	The *Energy Yield* was calculated based on VDI 4631

Modelling

The **BK- system** is a vertical fermenter, which is buried half in the ground. The fermenter is made out of PVC and the produced gas is stored inside at the top, before it is forwarded to the temporary storages and further to the Micro-Biogas-Grid. The used substrate needs to be thinned with water to homogenise the substrate and improve the pumpability. It is a one-step fermenter working at psychrophilic temperature conditions and a *Daily Load* of 0.87 m³ for farm A and 1.68 m³ for farm B. Heating systems, mixers or other devices for process control are not installed. The central power plant operates with 75 kW.

The **CDM- system** is a horizontal fermenter, which is dug totally in the ground. The soil is covered with a PVC membrane and the biogas is stored in a PVC based geo-membrane, installed above the cavity. The used substrate needs to be separated in a rust to avoid formation of floating or sinking layers. It is a two-step fermenter also working at psychrophilic temperature conditions and there is also no device for process control installed. The D*aily Load* is 8.12 m³ for farm C and 38 m³ for farm D. The biogas is compressed, counted and then used in the On-Farm power plant with 104 kW installed power.

To complete the **Technical Analysis** a survey of the four facility managers was carried out. The guideline of the interview was based on VDI 4631. The *Usable Fermenter Volumes* of the FFB BK and CDM fermenter were directly questioned. The *Total Lifetime* and the *Plant Availability* were determined by using data from the installed data logger at the power plants.

The **Economic Analysis** is also based on the survey. The *Investment Costs* and the *Running Costs* were directly questioned. In case of FFB biogas production the *Revenues* were calculated doing a comparison of the purified methane to the natural gas price and quality in Brazil. Additionally, the value of the digestate as fertilizer was considered. For the PFB farm the *Revenues* were calculated for the produced electricity, the digestate and generated CO_2 certificates.

The **Ecological Analysis** was based on the *Prevention of Methane* and *Olfactory Emissions*. The calculations for the methane emissions are based on the IPCC Guidelines for National Greenhouse Gas Inventories, while the olfactory emissions were subjective opinions of the four facility managers.

From the situation analysis technical, economic and ecological **Barriers** and **Optimization Potentials** are deduced. Development possibilities are shown and discussed separately for the FFB and the PFB concept.

Results

Situation Analysis

Table 3 shows the analysed technical parameters for FFB and PFB with a comparison to European values from practice primarily measured during the "Biogas-Messprogramm II" of FNR.

Table 3: Comparison of technical parameters in Brazil and Europe

	Parameter	Unit	Europe	Brazil			
1	Substrate			A	B	C	D
1.2	*Volatile Solids (VS)*	g/kg	100-290[3]	29	30	34	24
		n =	---				13
		SD =	---				7
2	Fermenter			A	B	C	D
2.1	*Usable Fermenter Volume*						
	Fermenter 1	m^3	---	18	36	324	806
	Fermenter 2 (PFB)	m^3	---		---		683
2.4	*Gas Composition*						
	CH_4	Vol.-%	45-75[4]	56	57	64	63
		n =	---	5			8
		SD =	---	2			1
	H_2S	ppmV.	-20,000[4]	64	167	>1,000	2429
		n =	---	4			8
		SD =	---	7			710
2.5	*Hydraulic Retention Time*						
	Fermenter 1	days	29-289[3]	21	21	40	21
	Fermenter 2 (PFB)	days			---		18
2.6	*Loading Rate*						
	Fermenter 1	$kg\ VS_{in}/(m_H^3\ d)$	2-3[6]	1.37	1.39	0.84	0.14
	Fermenter 2 (PFB)	$kg\ VS_{in}/(m_H^3\ d)$	2-3[6]		---		0.07
2.7	*Degree of Degradation*	%	46[5]	64	38	60	63
2.8	*Methane Yield*						
	Total	Nm^3/day	---		160		489
	per kg VS	$Nm^3_{CH4}/kg\ VS$	225-500[3]		---		249
	per $t_{substrate}$	$Nm^3_{CH4}/t_{substrate}$	16-206[3]		---		6
3	Gas treatment			A	B	C	D
3.1	*Desulphurisation to*	ppm_{H2S}	<1[5]		<1		---
3.2	*Purification to*	$\%_{methane}$	98[5]		96		---
4	Gas-Usage			A	B	C	D
4.1	*Electrical Efficiency*	%	31-42[3]		21		24
4.2	*Total Life Time CPP*	h_{total}	35,000[5]		48,000		8,000
5	Entire complex			A	B	C	D
5.2	*Plant Availability*	h/year	8,000[5]		3,204		2,957

The largest difference to Europe is the much lower content of *VS* in Brazilian fermenters. In the BK fermenter this is due to the thinning of substrate and in the CDM fermenter due to the installed separators. Therefore there is a low *Loading Rate* and a high *Degree of Degradation* with a following high *Methane Yield* per kg VS, but low per ton of substrate.

The FFB concept operates with *purification* to 95% methane, while removing nearly 100% of H_2S. The PFB concept has no purification facility installed and the *Desulphurisation* facility was not working.

The *Electrical Efficiencies* of the CPPs with about 25% are low compared to European standards, because they are not built for biogas-usage. At the FFB concept the CPP works about 15 years till it has to be replaced, while the PFB CPP works 3 years which is 77% less than European standards due to the high degree of H_2S.

The low *Total Plant Availability* at PFB concept with <3,000 hours per year results from the higher electricity demand respectively supply prices. The PFB farm operates the CPP primarily while it is used for self-supply.

In Table 4 the economic parameters are shown and also compared to European values from practice.

Table 4: Comparison of economic parameters in Brazil and Europe

	Parameter	Unit	Europe	Brazil			
1	Specific			A	B	C	D
1.1	*Investment costs*	€/$kW_{installed}$	1,529-6.140[3]		8,379		1,349
1.2	*Total cost*	€/kWh	---	0.61	0.45	0.33	0.20

The *Specific Investment Costs* of the CDM fermenter are low for the PFB farm. At the FFB farms the S*pecific Investment Costs* are more expensive due to the installation of the Mikro-Biogas-Grid. The S*pecific Cost of a kWh* is with 0.20 €/kWh at the PFB farm high and with 0.51 €/kWh for the FFB concept even higher. A *Payoff* under actual conditions is hardly possible.

Conclusion and perspectives

Barrier Analysis and Optimisation Potentials

Technically the *Hydraulic Retention Time* in BK fermenters has to be raised to improve the S*pecific Methane Yield*. In the CDM fermenter the content of *VS* has to be raised to improve the *Total Methane Yield*. Therefor a mixer is needed to avoid the formation of sinking or floating layers. Without the formation of layers the *Plant Availability* can be raised. Additionally a *Desulphurization* facility should be installed at the PFB farm to raise the CCPs Total Lifetime.

Economically for the PFB concept the implementation of a simple and cheap *Fertilizer Management System* is needed. At the moment the whole digestate is fertilized on 28 ha while the amount could supply nutrients to > 400 ha. At the FFB concept most of the biogas plants got just installed and a raise in the biogas production is to be expected. At actual conditions the investment costs are too high and have to be minimized for future Micro-Biogas-Grids.

Ecologically for the CDM- fermenter and the BK- fermenter a *Coverage* of the digestate pit is recommended to prevent methane emissions from the digestate.

Non-Technical barriers are connected to the political conditions. There is no *Regulation* for the energy companies to accept feeding electricity into their network and a system for S*ubsidies* does not exist. The low price of *CO_2- Certificates* causes lower investments in CDM projects. Further, there are no *Long-Time Experiences* referring to biogas in Brazil and the facilities managers mostly work on the base of own experiences.

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