An evaluation of the Potential Anaerobic Digestion Feedstock, Biogas yield size and its Management Impact on Rural Society in Bangladesh

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Abstract
This paper reports on findings from visits to experts in the field and a small scale survey undertaken in Bangladesh to evaluate what types of non-commercial Anaerobic Digestion (AD) plant were commonly used, what types of scenarios were found where they could be easily used more widely, and the current feedstocks, charging rates, biogas yields and attitudes of their user-managers and neighbors. Most common types of feedstock, feedstock application rate (daily charge) and existing biogas yield capacity were the main findings of this research. Background information on available AD facility types (small, medium and large) were found from the field visits and meetings with key government and non-governmental organizations of Bangladesh. After getting background information on the use of AD from the expert organizations, several biogas plant visits were carried out in four different districts of Bangladesh in different parts of the country. It was done to look at how the AD facilities are constructed, operated and funded and to collect views of the local people about the AD systems and their impacts on them. This was done through face to face interviews with 50 households of either biogas stakeholders or neighbour. Domestic-sized plant (2 - 5 m^3) was found to be the most common, even when smaller or larger ones would be more suitable. Those observed were found to be significantly underperforming, apparently due to lack of management knowledge of AD as well as poor condition of the cattle. Some of the perceived social impacts are reported.

Key words: Anaerobic Digestion, Feedstock, Biogas Yield

1. Introduction

Bangladesh has a land area of 147,570 square kilometres and is one of the least developed and densely populated countries in the world (Islam, 2006). Meeting all the basics in life, including provision of energy, is a challenge. The population of over 144 million faces problems like environmental degradation, shortage of food supply, reduction of soil fertility and scarcity of energy (World Bank, 2005). Bangladesh has one of the lowest rates of energy consumption per capita in the world. More than 55% of the country's energy requirement comes from traditional biomass energy sources which are crop residue, twigs, leafs, fire wood and dung cake (Netherland Development Organization-SNV, 2005). Traditional biomass energy is used mostly for cooking. Dung cake fuel is one of the

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important traditional uses of cow dung in Bangladesh. Excessive use of biomass energy causes deforestation and in the long run increases the propensity of environmental disasters like cyclones and floods, compromising agricultural productivity and economical development (Netherland Development Organization-SNV, 2005). Anaerobic digestion is an alternative option, producing a clean energy biogas and organic fertilizer.

1.1 Common waste scenarios in Bangladesh

Every day 3,500 tonnes of waste is produced in Dhaka, the capital of Bangladesh. This includes Municipal Solid Waste (MSW), agricultural waste and animal waste (cattle dung and poultry litter) which are the major sources (Sinha, 2010). Annually in Dhaka 511,000 tonnes of waste are disposed at simple controlled landfill with a further 509,248 tonnes lost or illegally dumped waste (Choudhury, 2009). In cities, the government and City Corporation collect only 42% waste for disposal in landfill and the rest lies on roadsides, near open drains, and in the low-lying areas of the city (Enayetullah, 1995) causing transmission of disease and green house gas (GHG) emissions (Dhaka City Corporation, 2004). No Anaerobic Digestion plants are known to currently use municipal waste.

In rural areas, according to a report by the Bangladesh Centre for Advance Studies (2005), the 8.44 million households of Bangladesh have 22.29 million cattle and buffalo and 116, 000 poultry farms which produce 22,139 tonnes of litter per day. Dung and litter have a big impact on the environment and cultivable land in Bangladesh, e.g. dumping of poultry litter on low ground near the farms causes significant odour, dust and surface water pollution (Waste Concern, 2005). Bangladesh has nearly 40,000 domestic Anaerobic Digestion plants using dung and poultry litter feedstock but SNV (2005) has estimated that there is a potential for more than 3 million.

1.2 Anaerobic Digestion in Bangladesh

Composting and anaerobic digestion serve to stabilise and reduce the mass of organic waste and to sterilise it. Anaerobic digestion (AD) is a biological process of the breakdown of organic matter by naturally occurring bacteria in the absence of air, and this produces biogas, and a solid digestate. Biogas comprises of mostly methane and carbon dioxide with a small amount of hydrogen sulphide and hydrogen. The richness of the digestate depends on the type of input material, but it can be a useful fertiliser. (Gofran, 2008).

Bangladesh has a suitable climate for biogas production. The ideal temperature for biogas is around 35^{o}C. The temperature in Bangladesh usually varies from 6^{o}C to 40^{o}C but the inside temperature of a biogas digester in Bangladesh remains at 22^{o}C – 30^{o}C, which is very near to the optimum requirement (Gofran, 2007).

The Bangladesh Council of Scientific and Industrial Research (BCSIR) and several other institutes like Bangladesh Rural Advancement Committee (BRAC), Local Government Engineering Department (LGED) and Division of Livestock Services (DLS) have made a joint agreement for research, training, and dissemination of biogas technology. In 1994, the government of Bangladesh created a public limited company named Infrastructure Development Company (IDCOL) with financial assistance from the World Bank to support all kinds of infrastructure development, with focus on energy-related infrastructure. These organizations, with the support from Netherlands Development Cooperation (SNV), launched a project for the extension of biogas technology in Bangladesh. Under this program, 36,450 biogas plants were due to be built. Grameen

Shakti (GS) operates many activities to promote, develop, and popularise biogas technologies in the remote rural areas of Bangladesh (Gofran, 2007).

2. Methodology

2.1 Overview

There are many different hypothetical scenarios where anaerobic digestion might be an effective way to manage waste and produce energy in a place where it would be useful. However, this study aimed to identify the most common situations, suited between them to use only the small number of easily available AD facility types (small, medium and large). It was intended to later carry out a large scale survey to determine the potential frequency of those scenarios in a specific district, and to then estimate biogas potential nationwide. Bearing this target in mind, exploratory field visits and meetings were carried out with key government and non-governmental organizations of Bangladesh which are key sources of data and are deeply involved with AD research through finance, field and lab activities.

After getting background information on the use of AD from the expert organizations, several biogas plant visits were carried out (N=11) in four different districts of Bangladesh in different parts of the country in 2009 to look at how the AD facilities are constructed, operated and funded, how the feedstock and products are used, and to collect views of the local people about the AD systems and their impacts on them. This was done through face to face interviews with the operators and neighbours. Interviews were held with 50 households of either biogas stakeholders or neighbour. The 11 AD farms visited were randomly selected but covered different sizes and feedstock (10 dung and 1 poultry litter).

From this small scale survey and related discussions it was possible to determine that three scenarios were common: small family-based cattle smallholdings, poultry farms, and commercial cattle markets in towns. These had potential for five sizes of AD plant. A later large-scale survey of N=125, N=125 and N=30 respectively was carried out. The full details of that work are reported elsewhere (Rahman et al, in preparation), but information relating to economic and social impacts which were the focus of the smaller survey are reported here.

2.2 Expert groups visited

Biogas and anaerobic digestion expert organizations Grameen Shakti, Advance Engineering, BCSIR and DLS were visited.

Grameen Shakti

Grameen Shakti (GS) is one of the largest and fastest growing rural-based renewable energy companies in the world. This organization provided a number of visits to AD sites for this research. It is a non-governmental organization working with the renewable energy program through microfinance. They started the biogas program in 2005 and GS's biogas program is the first market-based program in Bangladesh. GS used its Grameen Bank's experience to evolve a financial package based on instalment payments which reduced costs and helped it reach economy of scale. GS provided a number of AD sites for visits for this research.

Advance Engineering, Dhaka

Advance Engineering (AE) is a renewable energy research, development and manufacturing company established in 1997, which also provided experimental AD plant site facilities for this research. It is a non-governmental organization in Bangladesh involved in biogas appliances. AE operates continuous research on the development of biogas plants, economic use of biogas, different design of biogas burners, hajack light (locally used device for lighting), generators, portable reserves, community based biogas plants and low cost biogas plant.

Bangladesh Council of Scientific & Industrial Research (BCSIR)
The laboratory facilities in this research were taken from the Bangladesh Council of Scientific & Industrial Research (BCSIR) in Dhaka. It is a government organization. Current areas and major fields of research and development activities of the laboratories are analytical chemistry, tissue culture, biotechnology, polymer chemistry, arsenic mitigation, and production of chemical and allied products.

District Livestock Office and Division of Livestock Services
The Division of Livestock Service, Dhaka and the District Livestock Office in Gazipur are the two government sources offices which hold data and information on poultry and livestock numbers in the country and the district respectively. Various information was collected via personal interviews and telecommunication with relevant persons of these organizations.

3. Results and Discussion

3.1 Feedstock Types

Visits to the experts and existing AD plant, as well as related discussions and explorations, led the researchers to realise that two prospective feedstock types were unlikely to be immediately suitable for AD: municipal solid waste and hyacinths. Although municipal solid waste is available abundantly, there are currently no effective methods to separate out the organic components useful for AD. Instead, there will always be likely to be extensive contamination with non-organic materials. Furthermore, even within the organic component of such waste there is great daily variation, which cannot be handled well by microbes which generally prefer consistent feedstock.

A second waste stream that was considered was water hyacinths, which are a great problem in some seasons of the year, growing very quickly across water. However, as they are not available all year round, this feedstock was not considered further.

As well as the commonly known feedstocks of cattle dung and poultry litter, one of the authors also proposed a third common feedstock (Rahman et al, submitted): the rice straw from cattle markets held daily in towns. Typically the cattle are in good condition and contained, thus producing significant amounts of easily collected dung, mixed in with the straw of the rice straw feed and bedding containing much liquid waste.

3.2 Feedstock Quantities

Table 1 shows the reported daily amount of feedstock for different plant found in the surveys, and they are compared with the amounts as recommended in the operations manual provided by Grameen Shakti (GS). It is clear that the farmers used a lower daily charge compared to the required dose – 33% less. Inadequate number of cattle was the main reason given. It was also found during AD plant visit that the farmer didn’t charge the plant properly; they charged it 3 - 4 times per week whereas it is essential to feed the digesters every day, or the microbial growth is affected. Lack of knowledge appeared to be the reason for such type of poor management.

Table 1 Recorded information on surveyed AD plant and recommended input charges

Plant number	Feedstock	Plant size (Gas-m^3)	Actual daily charge (kg)	Recommended daily charge (kg) GS manual	Location (District)
1	Cow dung	3.2	50	87	Barisal
2	Cow dung	2.4	40	65	Barisal
3	Cow dung	14	262.5	378	Dhaka
4	Cow dung	14	262.5	378	Dhaka
5	Cow dung	3	40	80	Manikgonj
6	Cow dung	3.2	70	87	Manikgonj
7	Cow dung	2.4	30	65	Manikgonj
8	Cow dung	2.4	40	65	Manikgonj
9	Cow dung	2.4	40	65	Manikgonj
10	Cow dung	2.4	40	65	Manikgonj
11	Poultry litter	3.2	45	45	Mymensingh

3.3 Existing biogas yield capacity

Biogas yield rate for cattle and poultry feedstock in this research were found to be significantly lower compared to the Grameen Shakti published data (Table 2). The current yield efficiency can be determined by comparing observed results with the Grameen Shakti reference expected results.

Table 2 Existing biogas yield capacity compared with Grameen Shakti.

	Cattle Biogas yield (m^3)	Poultry Biogas yield (m^3)
This work	0.021	0.021
Grameen Shakti (Gofran, 2008)	0.037	0.071
Efficiency (this work/GS)	57%	29%

Compared to the Grameen Shakti manual (biogas yield and composition rate) results show the cattle smallholding AD plant and poultry farm AD were 57% and 29% efficient (yield efficiency). This might be due to the improper management of biogas plants by the rural stakeholders.

4. Discussion of factors affecting biogas yield

According to this research the biogas yield of for both cattle dung and poultry litter is 0.021 m^3/kg of feedstock. The biogas production rate according to the Grameen Shakti manual is 0.037 and 0.071 m^3/kg of feedstock for dung and poultry litter respectively. It clearly shows that the biogas yield is significantly less compared to the Grameen Shakti published data. This might be due to some operational factors and other general factors affecting biogas production, as discussed below.

4.1 Feedstock quality and amount of feedstock

The daily quantity of manure added must be sufficient, if too much or too little is added, very little or no gas will be produced as the bacteria does not have sufficient time to break down the manure. Under-feeding is the most commonly cited problem in rural Bangladesh (Gofran, 2010). Due to under-feeding and irregular feeding biogas yield was significantly less in dung and poultry based AD systems. Feedstock constituent also can cause a significant impact on biogas production. These were also noticed in this research during the survey.

From the 11 domestic biogas plants visited in this research it was found that only one plant (out of 11) was fed according to the required rate of feedstock. It means about 91% of biogas plants remain underfed. This result was supported by research conducted by the Institute of Sustainable Development (2010) on a number of AD plants in Bangladesh. It was found that 83% of the plants were underfed with 50% of the plants receiving less than half of their required dung. According to the survey, under-feeding usually occurs when the biogas plant owners sell a cow after the biogas plant is constructed. In most of the cases lack of proper training is an important reason of under or improper feeding (i.e. excessive water/dung ratio). Other malfunctions were caused by poor workmanship or sub-standard construction materials (ISD, 2010). Proper mixing of slurry is also an important factor for proper bacterial activity. Occasional stirring is required to help mix the manure which will accumulate gas and prevent the forming of crust (cow dung) or slurry (poultry manure) in the digester chamber.

Another factor that might affect biogas production severely is the quality of the feedstock. In this result biogas yield of poultry litter was 0.021 m^3/kg of feedstock whereas the GS manual biogas yield rate is 0.071 m^3/kg of feedstock. It shows that the present yield rate is only one-third in comparison to the GS manual biogas yield rate. This was due to the composition of animal food. During the survey it was observed that the experimental poultry AD farmer used to feed poultry food mixed with crushed mussel's shell which is rich in calcium. They do this to make the egg shells hard and increase egg production. Crushed mussel's shells cause a compact layer inside the digester and affect bacterial activity and reduce biogas production in the long run.

4.2 Present and future AD potential

A later survey was carried out with N=125, N=125 and N=30 smallholdings, farms and cattle markets respectively, and the full details of that study are reported elsewhere (Rahman et. al., under submission). However, a finding relevant to this paper is that only 11% of smallholdings and farms were found to have an existing on-site AD systems. 2.5% of them were from cattle smallholdings, 8.5% of them from poultry and none of them from cattle market rice straw. Every one of them was domestic in size – no medium or large ones were observed (Table 3).

Table 3 On-site biogas plants in Gazipur district, Bangladesh

Animal manure	Surveyed Farm	Existing AD	Notes
Cattle	125	7	Domestic size
Poultry	125	24	Domestic size
Cattle market rice straw	30	0	
Total	280	31	
% Existing AD plant		11	Domestic size

This means that the present AD feedstock utilization rate is very poor compared to its potential level of capacity. Table 4 illustrates the potential yield production and number of families each type of scenario could support for cooking uses.

Table 4 Estimation of the number of families whose daily cooking requirements can be provided for by the categorized AD size (assuming a family of 5 uses 44 MJ of energy/day).

	Biogas yield (m^3)				
	Small domestic (<2)	**Domestic (2 - 5)**	**Medium (5 - 25)**	**Large (25-150)**	**Extra large (>150)**
Cattle					
Energy MJ	29	57.0	232.0	n/a	n/a
Number of cattle	4	7	29	n/a 0.0	n/a
Number of Families	**0.7 (small)**	**1**	**5**	**n/a**	**n/a**
Poultry					
Energy MJ	n/a	93	270	1399	n/a
Number of birds	n/a	572	1614	8327	n/a
Number of Families	**n/a**	**2**	**6**	**32**	**n/a**
Cattle market rice straw					
Energy MJ	n/a	n/a	n/a	36750	108,000
Number of cattle/market	n/a	n/a	n/a	390	1150
Number of Families	**n/a**	**n/a**	**n/a**	**835**	**2,455**

Note that a size of plant even smaller than the domestic size of $2m^3$ is still very useful for small families. The poultry farms show great capacity to supply groups of households or even entire villages, and the cattle markets even greater numbers of families, suited to the fact that they are found in towns.

4.3 Impact of AD on rural community

Social impact

Biogas is a promising renewable source that could meet the energy demand of rural Bangladesh. In most cases it can meet the energy demand of neighbours and communities from the surplus gas. Domestic biogas plants have gained popularity as alternative energy sources in Bangladesh, but there are a growing number of slightly larger scale biogas plants operating on a commercial basis. Some of these biogas plants are generating electricity and some of the plant owners are selling biogas to their neighbours (Talukdar, 2010). Consequently, it is contributing towards social and community development.

Generally women cook food for the whole family in rural Bangladesh. Biogas produced from cattle dung and poultry litter is widely used as a cooking fuel (Van Nes Wim *et. al*, 2005). The use of biogas for cooking is cleaner, odour free and improves public health especially for the rural women and children. A study by Ghimire (2005) explained that interest in biogas technology in Bangladesh is growing due to the increasing awareness of the importance of renewable energy sources and their potential role in decentralized energy generation in rural areas. The rate of growth of biogas technology is expected to accelerate in the future in line with the realization of the importance of biogas in enhancing rural livelihoods.

Biogas production has no negative effects on the environment or on human health if properly managed. Proper management of a biogas plant could be ensured through the introduction of training in operating and repairing of biogas plants. There is also a reduction of workload, mainly for women since they are the ones who are responsible for collecting firewood and cooking. All of the evidence indicates that AD has a significant social impact on the community.

Economic impact

Domestic biogas programs are often justified on the basis of the private benefits and costs accruing to the individual households, in terms of providing a superior cooking fuel, improved indoor air quality and saving time spent on collecting firewood. For instance, Bala and Hossain (1992) evaluated the economics of biogas digesters in Bangladesh in terms of firewood and fertilizer values. The net present benefit was computed from the digester cost, kinetics of biogas production and nutrient contents in the treated slurry. The model was analyzed to test the sensitivity to changes in retention time, annual operation period, subsidy, price of fuel wood, construction cost, interest and inflation rate. It indicated that the total AD potential could be influenced by some important economic factors. The consumptive use of the biogas for cooking and the non-consumptive and indirect value derived from the biogas plant providing feedstock for other processes and other such benefits as greenhouse gas mitigation (positive externalities) needs to be accounted for. According to Gofran (2009) one biogas plant of 2.4 m^3 gas enables a saving of about 2.4 tonnes of biomass per year. Biogas is an efficient fuel among the other fuels used in Bangladesh for traditional cooking stoves. A survey analysis by SNV on 66 biogas plants showed that the average wood fuel saving is 156 kg/household/month (SNV, 2005). Talukder (2010) surveyed 30 biogas plants in order to investigate the types of biogas plants in Bangladesh. Out of the total 30 surveyed biogas plants, 78% of them had a plant size ranging from 2 to 10 m^3.

Income generation could be the main objective of commercial biogas plants. An interesting practice was seen in Bangladesh during the field visit. A bigger poultry farms was selling biogas to their neighbours by distributing it through pipe systems. They usually charge about 300 - 500 taka (£3 - £5) per month per family. This could also be a good source of income which eventually pays back the total cost of biogas in a shorter period of time (IDCOL, 2006). This study found one poultry and one dairy farm who were selling biogas to their neighbours by a flexible pipeline. Similarly another plant owner was selling biogas to 6 households from a 10 m^3 biogas plant. Each household used to pay 500 taka (£5) per month. His monthly income from biogas was 3000 taka (£30).

Furthermore, loans are an important tool in promoting biogas. Even if generous subsidies are available loans are often needed for poor rural households to be able to invest in something that has several years payback time. Loans can be granted from the government, banks and other financial institutions or NGOs (Biswas *et al* 2001; Nancy and Elaine, 2007).

Conclusions

Research was undertaken to fill existing knowledge gaps on the use of Anaerobic Digestion plants in Bangladesh including current trends and how efficiently plants are working. Results show that plants are not fulfilling their potential. The actual daily feedstock rate was compared with the recommended daily charge and results show that farmers are using 33% less than the required levels. This has a negative impact on biogas yield. Compared to the Grameen Shakti manual (biogas yield and composition rate) results show the cattle smallholding AD plant and poultry farm AD plant were only 57% and 29% efficient. This was due to the improper management of biogas plants by the rural stakeholders.

This work indicates that the potential for using commonly available AD plants in common scenarios is greatly under-utilized in Bangladesh. The data suggests that yield efficiencies of the few existing plant are low and can be easily improved.

This research provides crucial information for planning for businesses, civic authorities and national policy making. By considering these results and information, the government can plan, NGOs (e.g. Grameen Shakti) and international development organizations (e.g. SNV) can take initiatives, monetary organizations (e.g. banks) can see the relevance of funding. Integration of all these efforts could increase the provision of Anaerobic Digestion in Bangladesh and help meet the energy needs of Bangladesh.

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