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Determination of the Potential Impact of Domestic Anaerobic Digester Systems: A Community Based Research Initiative in Rural Bangladesh

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Abstract: This research examines the potential impact of domestic anaerobic digester (AD) systems adopted in Bangladesh and similar developing countries. Cattle dung and poultry litter feed stocks were specifically investigated, because these were freely available and plentiful to people living within agricultural areas of rural Bangladesh. Data was collected to ascertain whether these two representative AD facility types provide tangible social, economic and environmental impact that benefits homeowners. Primary quantitative and qualitative data was obtained by field data collection, and meeting with expert groups and stakeholders. Empirical analysis conducted revealed that variations were found in the biomass feedstocks available on different sites but also differences were apparent in terms of the operations and maintenance (O and M) systems of the biogas plants operated. The biogas and methane yield variation was also measured, and variations were found in the cattle dung and poultry litter AD yield capacity. Overall, 64% of feedstock was utilised, 91% of biogas plants remain underfed and energy yield efficiency was 57% from cattle smallholdings' AD and 28% from poultry farms' AD. These results showed that small scale AD can offer a significant impact upon rural lifestyles through augmented economics, improved social activities, relationship building with neighbours and improved lifestyle achieved via time savings accrued. These results could help rural entrepreneurs, AD equipment providers and government institutions to develop a road map to implement future AD installation on a much wider geographical scale.

Keywords: anaerobic digestion; biogas; Bangladesh; impact; energy; feedstock

1. Introduction

Over 168 million people (or 1139 people per square kilometre) live in Bangladesh, making it one of the world's most densely populated countries, yet, the country has a notable dearth of reliable energy sources. At present, each Bangladeshi citizen contributes a meagre USD $1888 towards gross domestic product (GDP), per annum [1], but this rate could grow exponentially in the advent of an economically viable and dependable source of energy supply. A typical rural household owns two to three cattle and one buffalo, but often animal husbandry falls short of developing nations' standards, and so food yields are similarly poor. Moreover, there are circa 75,000 poultry farms and 1000 cattle markets in Bangladesh [2], and the manure from these animals could provide a reliable source of clean energy to alleviate energy demand requirements for rural people. An uninterrupted energy supply is pivotal to ensuring sustainable economic growth within a nation—particularly in Bangladesh, where recent economic growth has contributed to the public's insatiable demand for energy [3]. Within Bangladesh, agriculture represents the predominant source of industrial activity, and as a consequence, biomass is abundant, thus providing a natural source of biogas production. More than 70% of Bangladeshi citizens live and work in rural locations, yet only 62.4% of these people have access to electricity. The abundance of biomass provides an enormous opportunity to change lives and fuel further economic development. Indeed, the statistics are compelling, and circa 2016, there were 102.6 million tonnes of cow dung and 12.9 million tonnes of poultry litter literally going to waste [4].

As a developing country, the literacy rate and gross domestic product (GDP) in Bangladesh is low, and this situation negatively impacts upon the new installation and maintenance of biogas plants [5,6]. Socio-economic issues often hinder progress towards sustainable development, and an analysis is required to gain a deeper and more meaningful understanding of these issues (e.g., support for communities). The national level biogas survey conducted in 2013 revealed that only 50% of occupants within households with biogas plants receive formal training about the operations and maintenance (O and M) of the plant, and often such constituents a mere day of training [5,7,8]. Given this prevailing socio-economic situation and the demand for clean affordable energy to engender sustainable development, it is imperative the environmental and economic impact of bioenergy generation from different sources of biomass is assessed. Therefore, this research assesses the potential impact of domestic anaerobic digester (AD) systems for sustainable rural development in Bangladesh.

2. Current and Future Energy Sources

2.1. Energy Status Bangladesh

Bangladesh has one of the world's lowest energy consumption rates per-capita in the world (i.e., 321 kWh) [9]. At present, natural gas is used to generate up to 83% of the nation's electricity (ibid), albeit, many households do not have access to electricity and only 3% of the population have access to natural gas. Most people depend upon biomass fuel and liquid petroleum gas (LPG) for cooking—even though LPG is incredibly expensive [9]. An imported cylinder of 12 kg LPG capacity costs 1100 taka to 1200 taka (£11–£12), but the retail price of LPG needs to be fixed as urged by Nasrul Hamid, State Minister for Power and Energy Bangladesh [10]. Up to 60% of Bangladesh's total energy capacity is consumed within the domestic sector and energy can be categorised into three thematic groupings viz: (1) Traditional; (2) commercial; and (3) renewable—each will be elucidated upon further in the proceeding sections (refer to Table 1).

Table 1. The state of energy reliance in Bangladesh.

Sector	Status	References
Traditional (biomass fuel) energy user	50%	[1]
Consumption biomass fuel annually	45 million tonnes	[2]
Access to Electricity	55%	[3]
Per capita electricity consumption	321 KWh (versus UK—5546 KWh)	[4]
Per capita commercial energy consumption	216 kg of Oil Equivalent	[5]
Contribution of renewable energy (biogas, solar and hydro)	176 MW equivalent power	[6]
Domestic biogas system (potential)	8.6 million cubic meter of biogas	[7]

2.2. Traditional Energy

Biomass constitutes the traditional source of energy within Bangladesh and includes wood and leaves, agricultural residues and animal dried dung cake—often burnt on a primitive stove within the household. In March 2002, an estimated 11,199 million tonnes of biomass fuels were supplied and consumed, mostly for domestic cooking purposes. However, the usage of traditional biomass can negatively impact upon both the public and the environment via, for example, deforestation, air pollution and respiratory disease [11]. Harvesting wood and animal manually is also laborious, time consuming and the energy produced is inefficient, because primitive stoves are used for domestic cooking purposes (where much of the heat produced is dissipated to the open air). Indeed, on average, rural households spend around five hours cooking per day and meeting this demand requires approximately three tonnes of biomass per year. Working on the premise that around 50% of households cook with traditional energy sources, then around 45 million tonnes of biomass fuel is required for cooking purposes alone per annum. The sheer volume of traditional biomass fuels needed is unsustainable and places a huge ecological burden upon biodiversity and forestry, and indeed, wood fuel consumption has already exceeded the natural forests' regenerative capabilities [12].

Rural people in Bangladesh constitute 76% of the population and regularly use a mud-built cylinder stove (placed on three raised plinths and situated above or below ground level) for cooking and heating purposes—refer to Figure 1 [13]. An opening between these plinths provides a convenient fuel-feeding port, whilst conversely, the remaining two openings provide flue gas exit ports. This mode of biomass cooking within domestic properties creates a significant volume of indoor air pollution and represents a major public health hazard for occupants [14]. This is because, traditional biomass fuels generate more pollution than comparatively cleaner alternatives, such as kerosene or biogas. The cumulative impact of burning biomass upon both the general public and environment dictates that new and/or alternative sources of energy production are urgently required in Bangladesh.

Figure 1. Typical example of a traditional biomass cooking stove [15] (reproduced with permission from Sowgath, 2015).

2.3. *Commercial Energy (Fossil Fuel)*

Bangladesh has a large reserve of natural gas resources (i.e., 439 billion m^3 or 15.5 trillion cubic feet), and consequently, commercial consumption of this reserve constitutes approximately 66% of all energy consumed. As of June 2000, over 110 billion m^3 of natural gas was produced [16] and was typically utilised for agricultural manufacturing, electricity generation and cooking in larger industrialised conurbations. However, it is not economically viable to install gas pipelines to rural communities. The remainder of commercial energy consumption relies upon small reserves of oil, coal and hydropower [17]. At present, Bangladesh is amongst the world's lowest consumers of commercial energy per person (i.e., 216 kg of Oil Equivalent (kg OE) per capita) [18]. To fuel transportation and lighting in rural areas, high speed diesel oil and/or kerosene oil are predominantly used. Over 3.23 million tonnes of petroleum was consumed in 2000—all of which was imported [19]. Similarly, yearly consumption of coal exceeds one million tonnes; and again, almost all of it is imported and used to fire brick kilns for housing and infrastructure development. Organic peat deposits are abundant within the country and reserves are estimated to represent 150 million tonnes. Unfortunately, peat extraction costs are currently exorbitant [20] and monumental environmental damage would be caused by burning peat. Against this contextual setting, it is glaringly apparent that alternative clean energy sources must be developed and implemented.

2.4. *Renewable Energy*

Renewable (or alternative) energy sources (for example, wind, hydro and solar) have the inherent capacity to provide alternative and sustainable green energy sources to meet Bangladesh's growing energy demand. Consequently, Bangladesh's government aim to install 3168 MW of renewable energy capacity by 2021. Progress made to achieve this target was represented by 176 MW from renewables as of 2015. Constituent contributors included energy generated from: Solar home systems (150 MW); photovoltaic (PV) arrays (16 MW); solar mini-grids (614 kW); and solar irrigation systems (1.6 MW). Wind power generated 2 MW, biogas generated 5 MW and biomass generated 1 MW [21]. This research therefore argues that given the scale of opportunity and abundance of materials available, biomass resources and advanced technologies that exploit their inherent potential (such as AD) constitute the greatest opportunity to generate renewable energy.

Combustible biogas is produced by anaerobic fermentation of organic materials. It is typically comprised of 60–70% methane (CH_4) and 30–40% carbon dioxide (CO_2) and is an odourless gas that burns cleanly and produces more heat per kg than kerosene or biofuels (e.g., fuel wood, charcoal or animal manure) [22,23]. These properties mean that biogas can only be used to generate electricity to power refrigeration, lighting, heating and ventilation. However, a typical family-sized biogas plant is appropriate for cooking and lighting only and to realise the full potential of this energy source would require a much larger system.

As a result of the aforementioned context, this research seeks to assess the potential impact of a medium sized domestic AD plant in Bangladesh. The work is founded upon the premise that biogas affords the optimal alternative to traditional biomass energy in terms of power generation capacity and minimal public and environmental impact. A coincidental, yet palpable benefit of biogas production is that the digestate by-product produced is a highly nutritious agricultural compost that can enhance the organic matter in farmland soil to stimulate greater crop yields [24]. Given the availability of different feedstocks and favourable climate conditions for AD, this research proffers that biogas energy generation could exceed that of other alternative renewable energy sources available.

2.5. Concept of Anaerobic Digestion

The natural biological process of anaerobic digestion occurs when microorganisms break down organic matter in environments that are deprived of oxygen (O). This natural process can be replicated to generate biogas using an underground airproof container—otherwise known as a digester. A typical AD digester in Bangladesh is often constructed using masonry (often handmade bricks)—refer to Figure 2. The digester requires organic waste as a feedstock and a reactor container where microbial (i.e., bacteria and archaea) reactions break-down the feedstock to produce methane and the digestate by-product [25]. A number of important O and M factors can either directly and/or indirectly affect the anaerobic digestion process and methane yield. For this research, a comparative analysis of biogas produced by both landfill and anaerobic digestion are evaluated [26].

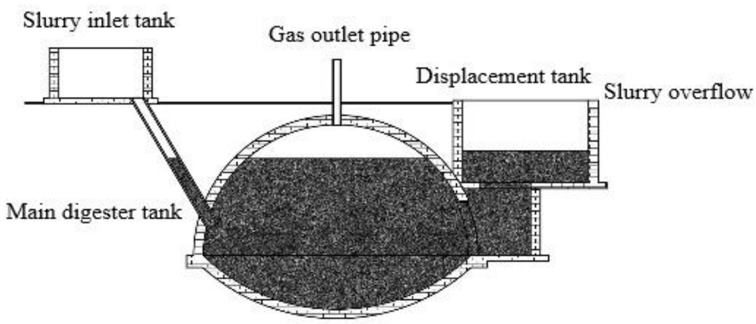

Figure 2. Example of a popular Chinese fixed-dome AD Facility [27] (Reproduced with permission from IDCOL, 2008).

3. Methodology of Research

The methodological design used a positivist and deductive epistemological lens to pursue the research aims and objectives previously defined and delineated. Within this overarching design, a waterfall operational process was adopted that consisted of a number of iterative key steps viz: (1) Meeting with expert organizations and field trips; (2) identifying the representative AD facility types; (3) reviewing potential yield efficiency; and (4) measuring the potential impact of AD in the rural community. Each step is now elucidated upon in further detail.

3.1. Meeting with Expert Organisations and Field Trips

Meetings with collaborating expert organisations sought to identify a small random sample of AD system types that would be representative of AD plants used within Bangladesh. These meetings and field trips involved influential government and non-governmental organisations such as: Grameen Shakti (GS), Advance Engineering (AE), Bangladesh Council for Scientific and Industrial Research (BCSIR), Netherland Development Organization (SNV) and Infrastructural Development Company Limited (IDCOL). Cumulatively, this pool of expertise contained sufficient tacit and explicit knowledge of the latest AD scientific breakthroughs and developments. For this collaborative research, a number of AD sites were provided by GS while experimental AD plant site facilities (using rice straw as the organic matter) were provided by AE. On-location laboratory facilities to generate primary data were provided by the BCSIR, Dhaka.

Secondary data and other information sources were obtained from collaborating organisations and were used for verification. The data collection instruments used included structured interviews with individuals and families but also interviews with personnel at collaborating organizations.

3.2. Identifying the Representative AD Facility Types

The density of households and feedstock types available in rural, urban and semi-urban areas varies significantly throughout Bangladesh. Using this knowledge, feasible and realistic simulations of AD scenarios can be propagated to represent the forecasts of present and future AD feedstock availability, and optimised distribution of future AD development sites. To generate realistic estimates that resonate with both the general public and politicians alike, AD facilities that best represent applications in Bangladesh were selected, and include: An AD facility located on a domestic cattle farm; and an AD facility located on a domestic poultry farm. The various types of AD feedstock were also reviewed and evaluated in collaboration with participating expert organisations.

3.3. Reviewing Potential Yield Efficiency

The potential biogas and methane yield of AD from potential waste biomass was studied by making a comparison between the practical and potential use of biomass. The collaborative partner GS provided a wealth of secondary data of biogas composition extracted from dung and poultry litter. Biogas yield and methane percentage of cattle dung is 0.037 m^3/kg feedstock and 60% respectively [28].

3.4. Measuring the Potential Impact of AD in a Rural Community

The feedback from different people located in different areas of a district was collected via surveys to discover the types of AD systems adopted. Selected farmers were interviewed, using a selection of key questions which covered the social, economic and environmental prospects of their respective community. The ambition sought to estimate the total available feedstock within that community and how it could be best used in a community based programme. The results generated were therefore based upon practical information. Variations in the practical and potential biomass effectiveness were also determined to assess the potential impact upon the rural community.

4. Results and Discussion

4.1. Biomass Feedstock

Nine domestic (ranging in size from between 2.4 m^3 to 3.2 m^3) and two medium sized (14 m^3 capacity) AD plants operated by GS provided sources of primary research data. One plant (with a size of 3.2 m^3) was fed with poultry droppings, with the remainder being fed with cattle dung. An average sized family of five people requires approximately 2 m^3 of biogas for cooking purposes per day [29].

The daily charge was estimated by multiplying the daily feedstock production per animal by the number of animals. The standard figures for the dung produced from a cow or bullock, a poultry bird and a cow held in a cattle market were 10 kg, 0.10 kg and 35 kg each [30]. According to these figures, a small holding with 5 cows produced 50 kg of wet dung daily.

When comparing between the on-site production of daily charge with the daily charge stipulated (cf. [31]), it is apparent that farmers under-feed their AD system (refer to Table 2)—specifically, farmers used on average 33% less manure than recommended. One reason offered was that either farmers did not have enough cattle or did not feed their cattle enough. It was also observed during the visits that many farmers did not feed the plants properly or frequently, and although they were instructed to feed their digester every day, many opted to feed it only three or four times per week. Amongst other things, a lack of labour resources, knowledge or training may be the reason for this type of poor O and M management.

Table 2. An estimate of the daily feedstock supply on-site.

Plant Number	Feedstock	Plant Size (Gas-m^3)	Daily Charge Primary (kg)	Daily Charge (kg) GS Manual
1	Cow dung	3.2	50	87
2	Cow dung	2.4	40	65
3	Cow dung	14	262.5	378
4	Cow dung	14	262.5	378
5	Cow dung	3	40	80
6	Cow dung	3.2	70	87
7	Cow dung	2.4	30	65
8	Cow dung	2.4	40	65
9	Cow dung	2.4	40	65
10	Cow dung	2.4	40	65
11	Poultry litter	3.2	45	45

Information based upon the biogas manual provide by Grameen Shakti.

In order to check the recommended figures, three experimental plants were chosen with biogas capacities of 2.4, 4.8 and 2 m^3. Sample feed stock types and plant sizes were chosen to be representative of the practical scenarios within Bangladesh (refer to Table 3). Post construction, a plant needs filling with fresh cattle dung, which supplies the anaerobic microbes. Once the plant starts generating biogas (after several days), it needs to be fed daily either with cattle dung or an alternative feed stock.

Table 3. Initial and daily feed stock charges used in three farm scale anaerobic digestion (AD) processes.

Feedstock	Plant Size (m^3)	Initial Charge (kg)	Daily Charge (kg)
Cow dung	2.4	3000	65 ± 2
Poultry litter	4.8	3000	67.67 ± 2.5
Rice straw	2	1300	17.67 ± 2

4.2. Use of Feed Stock by Farmers

Most of the dairy farms visited by the author had cattle populations of between three and 50 animals and their manure production was assumed to be between 30 and 500 kg per day. One poultry farm visited had a poultry population of 20,000 birds, and so its poultry dropping production capacity per day was taken to be two tonnes. The measured data showed that the farmer utilised only 45 kg of poultry droppings per day in the biogas plant in order to meet personal daily energy requirements. If the farmer becomes willing to share the gas generated with his neighbours, then the outcome of AD programme would have far greater, and wider reaching impact upon the rural community. This could also help to reduce environmental pollution, such as ammonia emission and eutrophication of local water sources.

It was found that most participating farmers did not use the maximum feed stock which their farm could generate. Overall, 64% of feed stock was utilised in the biogas plant in the eleven farms observed (refer to Table 4). Two reasons for this observed underutilisation were: (1) The farmer's lack of technical knowledge on AD O and M; and (2) the farmer's desire to fulfil their requirement for biogas energy only, rather than utilising the maximum energy that could be generated and sold to the wider community (as a secondary-to-farming revenue source).

Table 4. Recorded observations of the daily feed stock supplied on-site to the biogas plants visited and compared to the amount available.

Plant Number	Feedstock	Daily Capacity (kg)	Daily Use (kg)	% Use
1	Cow dung	50	50	100
2	Cow dung	40	40	100
3	Cow dung	400	262.5	66
4	Cow dung	500	262.5	53
5	Cow dung	80	40	50
6	Cow dung	100	70	70
7	Cow dung	50	30	60
8	Cow dung	40	40	100
9	Cow dung	60	40	67
10	Cow dung	120	40	33
11	Poultry litter	2000	45	2
Average				64

Following the visits to, and concomitant interviews with farmers, several participants intimated that they wanted to build bigger plants that could utilise their entire available biomass to generate additional income from gas sales to their neighbours through pipelines. The issues and/or the limitation for this idea revolved around a lack of potential funding sources to develop infrastructure to generate and distribute this energy.

4.3. Results from Experimental Tests

The measured gas production from the experimental biogas plants suggests that the GS data is overly-optimistic. The biogas production, and therefore the energy production, was lower than that suggested by the GS O and M manual (see Table 5).

Table 5. Daily Biogas Yield per Cow (Reproduced with permission from Gofran, 2008).

	Feedstock (kg/cow)	Yield (m^3/kg)	% CH_4	MJ/m^3 CH_4	m^3/Cow	MJ/Cow
This work	10	0.021	59.9	36.5	0.21	4.59
Grameen Shakti [29]	10	0.037	60	36.5	0.37	8.10
Efficiency (this work/GS)					0.57	0.57

Research results revealed that the actual biogas yields and energy capacity per cow is 0.21 m^3 and 4.59 MJ; this despite the GS manual quoting higher rates at 0.37 m^3 and 8.10 MJ. For poultry, a similar trend was apparent, with the actual biogas yield and energy capacity per poultry bird at 0.0021 m^3 and 0.0472 MJ respectively—this compared to the GS estimates at 0.0071 m^3 and 0.168 MJ respectively. Hence, using the GS manual, the findings illustrate that a show the cattle small holding AD plant and poultry farm ADs were 57% and 28% efficient. The various factors that affect biogas yield are now discussed in further detail.

In order to determine the potential impact of the use of AD in Bangladesh, it should be noted that data from different sources influences assumptions used in estimating operational, financial capacity and maintenance costs. Earlier research results revealed a potential of 2.4 million domestic AD plant from cattle small holding, 63,000 medium AD plant from poultry and 500 large sized AD plant potential from cattle market rice straw [28]. The total energy derived from these plants may need to be revised, based on these results.

4.4. Discussion: Impact and Factors

Table 5 illustrates that the actual biogas yield measured is significantly less than the reported GS data. Such recorded differences in biogas production may be due to a variety of operational factors including: temperature; initial feed amounts and daily feed rate; and the carbon-to-nitrogen (C/N) ratio and pH values of biodegradable organic matter which is subjected to the microorganisms' action [32]. These factors are now discussed in more detail.

4.4.1. Operational Factors

Research field trips to the eleven domestic biogas plants revealed that only one of these plants followed recommended fed rates, suggesting that an estimated 91% of biogas plants in Bangladesh remain woefully underfed. This finding concurs with research report findings published by the Institute of Sustainable Development [33] which identified that 83% of all plants surveyed were underfed and that furthermore, 50% of the plants received less than 50% of the recommended animal dung required. Reasons for this underfeeding were due to: Farmers/AD plant owners having an insufficient number of cattle—itself caused by the need to periodically sell cattle post biogas plant construction; and/or the poor quality of feed stock utilised. This may have been due to the composition of the food given to the chickens. For example, one participating poultry farmer used a blend of poultry food and calcium enriched crushed mussel's shell to increase the egg yield per bird and inherent strength of the eggshell itself. However, crushed mussel's shells inadvertently creates a build-up of an indigestible deposit inside the digester, which may affect bacterial activity because it occupies space which reduces operational volume and therefore biogas production.

4.4.2. Impact of Anaerobic Digestion in Rural Lifestyle

To increase the biogas production, rates will require a cultural transition within rural communities and will include: Increasing the level of formal education and training of farm workers, as well as empowering women to take a more proactive role in AD plant O and M. More specifically, rural communities should be educated in the environmental, economic, social and technological benefits to be accrued via the usage of efficient and effective AD plants, and moreover, how surplus energy creates additional income potential. Non-Governmental Organizations (NGOs) and Governmental Organizations (GOs) have an important role to play in this cultural transition and previous reports reveal that rural communities value and welcome their input [34].

4.4.3. Social Impact (Rural and Social Development)

Biogas has the innate potential to meet rural Bangladesh's energy demand and contribute to new wealth generation—as a tectonic shift away from subsistence farming [35]. For instance, surplus energy generated can be sold to neighbours, the wider community and industry—thus transforming the community and generating new wealth to power socio-economic national development. Domestic biogas plants continue to gain popularity amongst Bangladesh's rural community as a viable alternative energy source and opportunity to create additional wealth. In realisation of this opportunity, affluent and speculative developers have also begun to invest in a growing number of larger-scale biogas plants that operate on a commercial basis to either: Generate electricity or sell-on surplus biogas to neighbours [36]. Consequently, this activity and financial investment that accompanies it will support further innovations in engineering designs of AD plants, and over the longer term, lower costs and technology procurement for all to benefit.

Women represent the backbone and matriarch of rural Bangladeshi families and often cook for the whole family using animal manure as a cooking fuel [37]. In comparison, biogas, is cleaner, odour free and improves the health of domestic occupants who use (or are near the use of) it. Ghimire [38] suggests that Bangladesh's growing interest in the use and investment into biogas technology is due to the education of rural people who see the many palpable benefits of renewable energy sources and their quintessentially important role in decentralised energy generation in rural areas. Consequently, investment in biogas technology is set to rise exponentially.

Nevertheless, and despite benefits to be accrued, some issues in the use of biogas in rural areas of Bangladesh prevail. For example, Bangladesh could generate up to 12.26×10^8 m^3 of biogas per annum from human excreta [39] but there are significant barriers to its wide-scale implementation. First and foremost, people have negative connotations regards using gas generated from human excrement, but second, rural people do not wish to handle bio slurry by-products or plough such to fertilise fields and future crops [37]. Yet curiously, biogas generated from dung and poultry manure is generally considered as acceptable. Such attitudes can change over time, such as in Nepal, where the willingness to put human excrement into biogas plants increased over a generation [40].

Biogas production has no negative environmental effects, nor does it impact upon human health when properly managed by fully trained and educated owners. A significant benefit to rural communities is a concomitant workload reduction for women who are largely responsible for biomass harvesting and cooking. The body of knowledge available within extant literature, augmented by the findings presented within this paper, cumulatively confirm that AD can significantly transform rural communities for the betterment of all [41].

4.4.4. Economic Impact

Domestic biogas is often justified to households on the premise of its superior cooking performance, cleaner burning, and therefore, improved indoor air quality and labour saving accrued (via a reduction of time spent collecting biomass) (cf. [41]). Bala and Hossain (ibid) calculated the net present benefit from the digester cost, kinetics of biogas production and nutrient contents in the treated slurry. Their model indicated that the total AD potential is influenced by several economic factors, such as investment cost, loan availability, payback period and monthly/yearly instalment. The consumption of domestic biogas for cooking and heating as well as the indirect value derived from fertiliser materials for composting, together with other indirect benefits (such as greenhouse gas mitigation) must also be taken into account in monetary terms as positive externalities.

Gofran [31] suggests that one biogas plant that produces 2.4 m^3 of gas saves approximately 2.4 tonnes of biomass per annum. Using biogas in properly designed cooking stoves is more efficient than other solid biomass fuels used in Bangladesh. Indeed, biogas has a 99% combustion efficiency rate but the overall efficiency of biogas in a properly designed stove is 57%—such compares well against LPG at 54%, kerosene at 50%, fuel wood at 23%, crop residues at 14% and dried dung at 11% [41].

A calculation by BP Target Neutral (BP neutral), based on work by Kountouris et al. [42] (2014), and applied to a domestic biogas programme in India, suggests that every tonne of fossil carbon saved is worth $304. This includes an estimate of $276 saved from improvements in health. A typical domestic biogas plant saves about 2 tonnes of carbon per year, which suggests it saves $608 worth of carbon per year.

The Netherland Development Organisation (SNV) funded a biogas project and conducted a follow-up survey of 66 biogas plants in Bangladesh and illustrated that the average wood fuel saving was 156 kg/household/month [16]. In other research, Eusuf [43] revealed very few large farmers, owner-cultivators and landless labourers purchase fuel for cash, and that owner-cultivators and landless labourers opt to purchase dung sticks and wood fuel. During the past two decades, Bangladesh's rural communities have witnessed an erosion of their real incomes. This is because during the rainy season, cooking fuels purchased can constitute between 30 to 50% of their monthly income—leaving limited finances for other essential times.

The survey of biogas plants in Bangladesh by Talukder (cf. [36]) observed that of the 30 plants studied, 78% of them had 2 to 10 m^3 plant capacity. For larger commercial plants, income generation represented the main ambition and in Bangladesh's largest poultry farms; an additional income stream has been created through the sales of biogas to their neighbours. Typical biogas charges to rural families oscillate around 800–1000 taka (£8–£10) per month and this steady income stream ensures that pay-back of installation costs occur over a shorter period of time [28]. For example, this present research study found a singular poultry and similarly, another dairy farmer selling biogas to their neighbours via an innovative and affordable flexible pipeline. Other plant owners were observed to be selling biogas to up to six households from a singular 10 m^3 biogas plant; each household had to pay 500 taka (£5) per month for this instantaneously biogas service, thereby generating 3000 taka (£30) for the farmer. According to an estimation provided by Islam [44,45] the total cost to build a sand cement, brick made fixed dome biogas plant (Figure 3) having biogas capacity 10 m^3 (a day) is around 250,000 taka (£2400). Many biogas plants are purchased by poor rural households via loans offered by the government, banks/financial institutions or NGOs—even when generous subsidies are available [45–47].

Figure 3. Typical example of a biogas supplied via flexible pipeline in India [48] (reproduced with permission from Reddy, 2015).

Placing this present discourse within a wider holistic context, it is clear that an important relationship exists between renewable electricity generation and climate change. For example, a study conducted by the National Rural Electric Cooperative Authority, NRECA's [49,50] revealed: (1) A strong negative correlation exists between greater electrification output and a notable decrease in fuel costs; and (2) a strong positive correlation between greater electrification and increases in household income. These relationships form a solid basis upon which further local community development can be based. However technical education systems (for local leaders) of the local community would be useful for a continuing biogas programme development.

Bhattacharyae et al. [48] conducted a wider analysis, comparing the use of traditional biomass energy technologies in seven Asian countries (China, India, Pakistan, Nepal, Philippines, Sri Lanka and Vietnam). The findings (ibid) revealed that total biomass savings exceeded 322 million tonnes per year—this supported previous work that found that an initial investment into renewable energy technologies tripled the value of official development finance provided in many developing nations [51].

4.4.5. Environmental Impact (Ecological/Biodiversity)

The installation of an AD plant can replace traditional wood fuel for cooking and create a cleaner local environment by reducing smoke pollution in the indoor air improvement and improve sanitation and pathogen removal from the animal droppings (Figure 4) that are fed to the plant.

Figure 4. Roadside waste dumping in Dhaka (**left**) and dumping of poultry litter adjacent to water courses (**right**) [31]. (Reproduced with permission from Gofran, 2009).

Current and previous research work [28] shows that dung from cattle small holdings is mainly suitable for domestic sized AD plants, while wastes from poultry farms are more suitable for medium sized plants. Wastes from cattle markets can be used in large or extra-large AD plants. We can categorise the AD plant sizes according to their daily biogas yield capacity as: Small domestic (<2 m^3), domestic (2–5 m^3), medium (5–25 m^3), large (25–150 m^3) and very large (>150 m^3).

Table 6 reports upon estimates of the number of families that can meet their energy requirements, together with the number of livestock required to feed different sized AD plants. For instance, biogas yields from plants built on cattle small holdings are suitable for one to five domestic families. Larger AD plants that utilise poultry manure produce sufficient biogas gas to supply two, six and 32 families, depending on the size of the farm. Cumulatively, these findings suggest that medium community based AD provide sufficient energy for rural communities. Digestate (bio-fertilizer) from AD replaces the excessive use of chemical fertiliser, which have adverse impacts (Figure 4 and Table 7) on the ecosystem. Bio-fertilizers use for sustainable agriculture and at the same time save money; for example, through the replace to use of urea (chemical NH_2-CO-NH_2) fertilizer.

Table 6. Daily estimation of biogas yield required to support families of varying size.

	Biogas Yield (m^3/day)				
Cattle	**Small Domestic (<2)**	**Domestic (2–5)**	**Medium (5–25)**	**Large (25–150)**	**Extra-Large (>150)**
Energy MJ	29	57.0	232.0	0.0	0
Number of cattle	4	7	29	0.0	0
Number of Families	0.7 (small)	1	5	0.0	0
Poultry					
Energy MJ	0	93	270	1399	0
Number of birds	0	572	1614	8327	0
Number of Families	0	2	6	32	0

NB: Where a typical family of five requires 44 J of energy per day.

Table 7. Potential impact of different AD facility types.

Feedstock	Social	Economic	Environment	Remarks
Cow dung	Make life easier, save time	Microfinance in rural people	Reduce emission	Domestic-Mostly one house one plant
Poultry litter	Establish a good relation with the neighbour	Save money by sharing gas through pipe	Odour control and emission reduction	Domestic-Medium, Community based AD plant

5. Conclusions

The manure from the majority of the cattle small holdings is suitable for providing feed stock for domestic sized AD plants, which provide cooking fuel for a typical family. The droppings from a typical poultry farm can be used to provide feed stock for a medium sized plant and the gas produced can be shared between several families. Cattle and poultry manure represent the two most abundant biomass feed stocks for AD in Bangladesh. However, a significant lack of people's knowledge about the opportunities that AD provides means that the energy output from these resources is considerably less than the innate potential offered by this biomass. Community based AD projects offer rural entrepreneurs an opportunity to install energy generating capacity at their premises, so biogas could be sold to local people. Greater access to affordable microfinance would facilitate implementation of these ideas, because most rural small holders would probably be unable to afford the construction of medium sized AD plants. Notably, the development of this category of AD plant would have an enormous impact upon a large number of rural poor families, both financially and in terms of laborious labour savings made. While the main use of biogas is for cooking, it can also be used for lighting.

The feed stock available from a typical poultry farm in Bangladesh exceeds the amount required for a domestic AD plant. An overall 64% of feed stock was utilised in the biogas plant and 91% of biogas plants remain underfed. When compared to the manual of biogas yield and composition rate, the results recorded illustrate that a cattle small holding AD plant and poultry farm AD were at 57% and 28% yield efficiency, respectively. Consequently, it is better to build a medium sized AD plant and use the biogas energy produced to provide cooking fuel for a cluster of families. Results also reveal that biogas yielded from a cattle small holding can provide sufficient cooking fuel for one to five families, and this is considered to be mainly in the domestic AD category. Biogas plants using droppings from poultry farms produce sufficient gas to be shared by two, six or even 32 families, depending on the size of the farm. That suggests that medium community based AD is feasible. The biogas could be supplied from the poultry farm to neighbouring households through pipelines. A community of practice (consisting of a number of families) could therefore benefit from an AD facility feed by poultry (vis-à-vis bovine) manure. Knowledge and wisdom generated within this research will enable rural communities to maximise the production of biogas from existing feedstock to sustainably support rural families and create invaluable/additional sources of new finance and further national development.

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