

Assessment of Environmental Impact and Economic Viability of Domestic Biogas Plant Technology in Bangladesh

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Abstract

The study investigated the distinct environmental impacts and economic viability of domestic biogas technology in the countryside of Bangladesh. The study was carried out by a survey through personal interviews with biogas users. Seventy households were selected purposively and interviews were conducted through semi-structured questionnaires. The study mainly highlighted the potential reduction of greenhouse gas (GHG) emission and economic benefits of biogas utilization which were evaluated considering the substitution of traditional biomass fuels, by saving Liquefied Petroleum Gas (LPG) and cost of chemical fertilizer, and carbon trading. The economic benefits are addressed using some well-known economic indicators like Net Present Value (NPV), Payback Period (PBP), and Benefit-Cost Ratio (BCR). The results of the study revealed that a small-scale household anaerobic cow dung biogas digester not only exhibited the potential to cut carbon emissions on average by about 7.8 tons of CO₂ equivalents yearly, but it also demonstrated the economic feasibility of doing so as the value of NPV and BCR was positive. This study recommends that the government approach, awareness program, and continuous and proper performing of the biogas technology are needed to intensify the multiples environmental benefits of the technology.

Keywords: biogas, domestic digester, cow dung, bio-slurry, GHG emission, economic evaluation

1. Introduction

Energy, undoubtedly, is a pre-requisite for an entire nation's economic activities and social development (Ahiduzzaman and Islam, 2011; Rajendran et al., 2012; Uddin and Taplin, 2006), and one of the most crucial strategic commodities has long been the energy that has direct linkages with economic security, social security and environmental sustainability (Abbas et al., 2017; Ahuja and Tatsutani, 2009; Amin, 2015).

Bangladesh is one of the energy poverty (limited electricity and smoky cooking systems) (Khan et al., 2014; Rahman et al., 2014) and the world's most densely populated countries. In the country, about 116 million people (72% of the total population) live in rural areas (Amin and Rahman, 2019). About 47% and 6% of people in Bangladesh have access to electricity and natural gas, respectively, however, the service is not at a satisfactory level even though the government has also started importing Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) to meet the demand for household energy consumption. But importing LPG and LNG may not be an optimal long-term solution in the context of Bangladesh (Amin and Rahman, 2019). Furthermore, there is no natural gas pipeline connection throughout the rural and remote areas of the country. As a result, the rural people use traditional biomass energy sources for cooking (i.e., firewood, agricultural waste, and cow dung, etc.), which is about 62% of total energy consumption in Bangladesh (Foysal et al., 2012; Khan et al., 2014). However, direct combustion of biomass caused serious environmental degradation problems such as indoor air pollution, deforestation, and superfluous emissions of tons of greenhouse gas (GHG) which affects the environment locally and globally (Abbas, 2013; Katuwal and Bohara, 2009; Yu et al., 2008). As a result, the country's environmental well-being continues to be harmed by the widespread use of conventional biomass fuels for cooking (Mengistu et al., 2016).

Biogas, a renewable energy source, has become popular not only for the substitution of other fuels but also for

environmental and socio-economic benefits (i.e., preventing deforestation, reducing the necessity of purchasing fuel for cooking, the reduction of odor, the manufacturing of bio-slurry as a fertilizer replacing the chemical fertilizer, and limiting the GHG emissions) (Bentzen et al., 2018; Bruun et al., 2014; Gabisa and Gheewala, 2019; Gautam et al., 2009; Haryanto et al., 2017; Iqbal et al., 2014; Mengistu et al., 2016; Yu et al., 2008). Biogas is comprised of 60%–70% methane (CH_4) and 30%–40% carbon dioxide (CO_2) produced by waste materials, particularly, cow dung. Subsequently, it is adopted as a least-cost technology with its diverse advantages such as a waste recycling tool, and production of clean energy and bio-fertilizer (Katuwal and Bohara, 2009; Kinyua et al., 2016; Rahman et al., 2014; Rahman et al., 2018). Most of the biogas plants in Bangladesh are built based on small-scale cattle farms that only used their cow dung in the plants (Khan and Martin, 2016; Rahman et al., 2017). At present, cow dung available from 24.48 million cattle is nearly 244.8 million tons (10 kg per cattle per day) in Bangladesh (Amin and Rahman, 2019; Gofran, 2004). According to the Institute of Fuel Research and Development, our country has a potential of about 4 million biogas plants that can produce 105 billion cubic feet of biogas annually, which is the same as 1.5 million tons of kerosene or 3.08 million tons of coal (Iqbal et al., 2014). But unfortunately, the majority of farmers in Bangladesh simply gather the manure and stack it near the pens. After six months, the manure is collected and dispersed on the fields to be utilized as compost. This traditional use of dung has a big impact on the environment and cultivable land in Bangladesh because, during the stacking stage, an anaerobic process occurs inside the stacked dung, emitting methane as well as a foul odor, dust, and polluting of surface water (Salam et al., 2018). Thus, Bangladesh has huge potentials for developing biogas technologies in rural areas and one major benefit of anaerobic digestion (AD) is to mitigate GHG emissions from cow dung and other sources even from traditional biomass burning (Ghimire; Iqbal et al., 2014). In addition, Bangladesh can earn foreign currency through the Clean Development Mechanism (CDM) under the Kyoto Protocol by reducing GHG emissions using biogas.

There are around a dozen related peer-reviewed studies from Africa and Asia that are particular to the environmental consequences of household biogas technology (BT) at the global level (Amare, 2014; Gabisa and Gheewala, 2019; Haryanto et al., 2017; Hou et al., 2017; Katuwal and Bohara, 2009; Lansche et al.; Laramée and Davis, 2013; Mengistu et al., 2016; Pathak et al., 2009; Shane and Gheewala, 2017; Yu et al., 2008; Zhang et al., 2013). China is a leading country that inaugurated the utilization and benefits of BT; most of their studies were focused on the estimation of GHG reduction by energy substitution. It was reported by some authors that a domestic biogas plant can reduce the GHG emission with a range from 1.3 to 9.7 tons of CO_2 equivalents (CO_2e) (Katuwal and Bohara, 2009; Laramée and Davis, 2013; Pathak et al., 2009; Zhang et al., 2013). Furthermore, several studies estimated the GHG emission reductions considering the final energy uses rather than the entire life cycle of a biogas plant (Amare, 2014; Lansche et al.; Mengistu et al., 2016).

At the national level, Mainali et al. (2017) estimated the GHG emissions reduction potential of a layer poultry farm through BT using the poultry litter. Rahman et al. (2017) conducted a study on GHG mitigation capacity of small-scale BT using cow dung which estimated 11 tons CO_2e per year from cow dung and bio-slurry. However, there is a paucity of empirical evidence on the environmental effects such as GHG emission reduction from cow dung used in biogas plants in Bangladesh. To the author's knowledge, there is no published data of GHG emission mitigation through BT considering biomass fuel and LPG burning in Bangladesh. Therefore, the study aimed to investigate the overall GHG mitigation capacity and economic viability of domestic biogas plant technology in Bangladesh.

1.1 Description of the Study Area

The research was conducted from January to June in 2019 purposively in two Upazilas (sub-districts), Gabtali and Shibganj, of Bogra district in the north of Bangladesh, which were are-based rural areas where there are no natural gas supply pipelines. Bogra district is located approximately between 24°69' North latitudes and 89°45' East longitudes. Most of the rural population was involved in semi-subsistence agriculture, and households typically own at least one dairy cattle, commonly stabled both day and night, and practice integrated farming methods where manure is used for crop production. Non-Governmental Organizations (NGOs) performances were intensive on implementing family-scale biogas plants in the region. Additionally, maximum households involved with biogas production using an average of only four cows dung daily in the study areas.

2. Method

The study incorporated data on bioenergy and biogas potentials from earlier studies published in Bangladeshi and other international journals. In addition, some equations and calculations that were performed in different studies to determine the available potential were used to assess environmental and social impacts. Field surveys were also conducted to acquire some of the data for the existing biogas facilities. Finally, we estimated the GHG emissions

potential and their reduction prospects, using the equations, with collected field data from the studied sites.

To avoid any misinterpretation, questions were first formulated with respondents' perspectives in mind. Second, jargon, slang, ambiguity, uncertainty, emotional language, prestige biases, double-barreled questions, frightening questions, incorrect premises, and double negatives were avoided during questionnaire development. Ten interviews were conducted before the real data was collected to pre-test the correctness of the interviewing schedule. During pre-testing, certain errors were discovered. As a result, a few changes were made to improve the authenticity of the data collected. The researcher double-checked each interview schedule for probable inaccuracies and missing entries. We avoided any bias of findings in such ways.

2.1 Data Collection

A survey was conducted purposively with a total of 70 biogas users' households through a semi-structured questionnaire. The purposive data were gathered from both primary and secondary sources. Face-to-face interviews were conducted to collect primary data. The questionnaire decorates on costs and benefits of a biogas plant, current, and past fuel use, various perceptions (knowledge, attitude, preference) of biogas users, application of biogas and bio-slurry, and environmental issue of community. Some of the data were acquired from appropriate research and relevant office records and reports, published journals, Statistical Yearbook of Bangladesh, Bangladesh Economic Review, Department of Livestock Service, and NGOs. Various conversion determinants were also gathered from a variety of secondary data sources. The survey's purpose was to determine the household satisfaction level with the technology employed, bottlenecks encountered during plant operation, and the amount of bio-slurry used as a by-product. For analysis, variables and their categories were coded.

2.2 Biogas Generating System in Studied Areas

The fixed dome digester model, also known as the Indian model, was used in the studied area, with a digester at the bottom and a non-transferable gasholder at the top. After gathering more slurry, farmers applied it to the cropland. The moisture content (> 80%) of bio-slurry makes it ideal for growing vegetables all year. Usually, for producing biogas, household members manually mixed cow dung and water in the mixing tank, which is collected from the barn and brought from the motor or tube well respectively. In most of the households, the digester was placed close to the barn so that the cow manure could straightforwardly be directed to it after cleaning the shed. The biogas is transported to the house's biogas stoves via a plastic pipe. It was settled adjacent to the house to save the money on piping and gas lost during transfer. The gas is used during cooking which replaces the previously utilized fuels (i.e., cow manure, wood, and residues). The bio-slurry produced as a by-product replaces an equivalent quantity of chemical fertilizer and lowers emissions connected with its manufacturing and application. The biogas produced replaces an equivalent amount of biomass fuel, resulting in lower emissions from biomass burning.

2.3 Quantification of Fuel Saved by Biogas Utilization

During the interview, daily biomass (firewood, residues, and cow dung) use by all sample households was recorded at amounts that are used for cooking per month in absence of biogas digesters and then estimated the total amount of biomass used in a year multiplied by the market price of fuelwood showed the total cost of fuel consumption of each household and also measured the emission of fuelwood that caused climate change. Liquefied petroleum gas (LPG) was self-reported by respondents. Replacement of LPG by household biogas digesters provided economic benefits of a biogas plant in the study areas.

2.4 GHG Emissions Potential

Only the most potent GHGs (i.e., CO₂, CH₄, and N₂O) were considered to calculate GHG emission reductions (Yu et al., 2008). This study used the global warming potentials (GWP) of these gases over a 100-year time horizon, which were modified into 1, 25, and 298 in the fourth assessment report, respectively (IPCC, 2007).

2.4.1 GHG (CH₄) Emissions from Cow Dung Management in Studied Areas

Emissions that are mostly generated are methane from cow dung which is used in producing biogas at each of its life cycle stages. IPCC (2006) volume 4 chapter 10-guideline was used in estimating the emissions from cow dung. Methane is emitted at different stages of biogas production. At first, the methane starts to be emitted during the natural process of digestion by the livestock, which is called enteric fermentation followed by emissions during cow dung management. The emission from enteric fermentation is avoided here since there is no method to limit the emission from normal metabolic activities. The emission during cow dung management was calculated using the equation (1).

$$E_{\text{CO}_2\text{e}} = \text{YC} \times P_{\text{CH}_4} \times \text{GWP}_{\text{CH}_4} \quad (1)$$

Source: (Mengistu et al., 2016): pp.134

Where: E_{CO_2e} = Average annual emission of methane from the biogas digesters in kg of CO_2e ; YC = Yearly average biogas generation value from the digester size in kg, given the daily average biogas generation = 1.2 m^3 (Khan and Martin, 2016), and 1 m^3 biogas = 0.7 kg (Pathak et al., 2009); P_{CH_4} = methane's volume fraction in biogas, which is about 60% (Mengistu et al., 2016); GWP_{CH_4} = GWP of methane in CO_2e which is 25 (IPCC, 2007).

Secondly, methane might be released during the digestion of cow dung in the biogas generating system. As anaerobic digestion has occurred and methane emissions are prevented here, the only leakage is considered an emission. The following equation (2) is how the leakage was estimated:

$$CH_4 = CH_4 \text{ Produced} \times \left(\frac{1}{CE} - 1 \right) \quad (2)$$

Source: (Feng et al., 2009; IPCC, 2006)

Where: $CH_4 \text{ produced}$ = Biogas production in a digester per year, $\text{m}^3 \text{ y}^{-1}$ and CE = Methane collection efficiency [0.975 for fixed dome (IPCC, 2006)].

2.4.2 GHG (CO_2) Emissions from Fertilizers in Cropland

CO_2 emissions are reduced when bio-slurry is used instead of chemical fertilizer that would otherwise be produced by fertilizer use. The CO_2 emission was computed using the following equation (3). In addition, biogas slurry saves the use of nitrogen (N) fertilizer which would reduce the emission of nitrous oxide (N_2O), which is also evaluated.

$$E_{CO_2e} = (N \times GWP_N) + (N \times N_2O-N \times GWP_{N_2O}) + (P \times GWP_P) + (K \times GWP_K) \quad (3)$$

Source: (Haryanto et al., 2017; Pathak et al., 2009): pp. 413, 32

Where: E_{CO_2e} = Emission of CO_2e from fertilizer; N = Amount of nitrogen fertilizer; GWP_N = Global warming potential for N production (CO_2e/kg); N_2O-N = N_2O emission factor for N application (kg/kg); GWP_{N_2O} = Global warming potential for N_2O (CO_2e/kg); P = Amount of phosphorous (P) (kg/Y); GWP_P = Global warming potential for P production (CO_2e/kg); K = Amount of potassium (K) (kg/Y); GWP_K = Global warming potential for K production (CO_2e/kg).

2.4.3 GHG (CO_2) Emission from Traditional Fuel Use

CO_2 emissions from biomass combustion: The quantity of CO_2 emitted to the environment is determined by the type of fuel used as an energy source (Junior and Bank, 2017). So, emissions from the traditional burning of manure and firewood were calculated using equation (4).

$$CE_i = \sum_{i=1}^n Q_i \times C_i \times O_i \times \frac{44}{12} \quad (4)$$

Source: (Gabisa and Gheewala, 2019): pp.450

Where: CE_i = CO_2 emissions from biomass resource (ton CO_2), Q_i = Quantity of biomass resource consumed (ton), C_i = Carbon emission factor of biomass type, O_i = Carbon oxidation rate of biomass type (%). Carbon emission factors and the rates of carbon oxidation are shown in Table 1.

Table 1. Carbon emission factors and the rates of carbon oxidation of different biomass fuels

Biomass type	Carbon emission factor	Carbon oxidation factor
Firewood	0.45	0.87
Dung	0.40	0.85
Residue	0.39	0.85

Source: (Pei-dong et al., 2007; Shane and Gheewala, 2017)

CO_2 emissions from LPG usage: CO_2 emissions from the yearly consumption of non-renewable energy fuels such as LPG were derived from equation (5). The results of the emissions were expressed in $kg \text{ } CO_2e \text{ household}^{-1} \text{ year}^{-1}$. The heating value and emission factors used for non-renewable fossil fuels are presented in (Table 2).

$$CE_i = \sum (EF \times Activity) \quad (5)$$

Source: (Baul et al., 2018): pp.602

Where CE_i = CO₂ emissions from LPG burning, EF = Emission factor of the LPG, Activity = Amount of LPG consumed (kg) in a year

Table 2. Heating value and emission factors used for non-renewable fossil fuel

Non-renewables	Heating value	Emission factor a (kg CO ₂ eq kWh ⁻¹)
LPG	6.66 kWh l ⁻¹	0.241

Source: (IEA, 2010)

2.5 Life Cycle of GHG Emission Reduction

Biogas as a biomass energy substitute minimizes GHG emissions throughout its life cycle in rural households. With the substantial role of bio-slurry, the quantity of chemical fertilizer required on farms is reduced when biomass energy sources are replaced. As a result, it can be expressed as an equation (6).

$$GHG_{red} = (GHG_{CM} + GHG_{FA} + GHG_{FC}) \quad (6)$$

Source: (Gabisa and Gheewala, 2019): pp.450

Here: GHG red= GHG emission reduction, ton CO₂eq y⁻¹, GHG_{CM}: GHG emission from cow dung management, ton CO₂eq y⁻¹, GHG_{FA}= GHG emission from fertilizer application, ton CO₂eq y⁻¹, GHG_{FC}= GHG emissions from fuel (biomass and LPG) burning, ton CO₂eq y⁻¹.

2.6 Economic Analysis of Biogas Production

The construction of biogas digesters in rural areas has the potential to not only generate renewable energy but also to assist households by assuring a cleaner environment, better disease control, and economic growth (Gabisa and Gheewala, 2019). Economic evaluation through cost-benefit analysis is a widely used analytical tool for comparing the benefits and costs of interventions (Hutton et al., 2007). Different academics utilize several variables to assess the economic sustainability of rural household biogas plants. The majority of the researchers evaluated the system using well-known economic concepts like Benefit-Cost Ratio (BCR), Net Present Value (NPV), and Payback Period (PBP) (Gabisa and Gheewala, 2019).

2.6.1 Benefit-Cost Ratio (BCR)

A digester's BCR is used to analyze whether or not a project is cost-effective. The project is economically viable if the BCR is bigger than unity. It will also assess the project's overall financial impact, which we can all understand. The project's expenses and benefits were calculated. A constant price method was employed to calculate future costs and benefits, which assumes that present benefit and cost prices will remain constant. It is a valid measure for calculating future costs and benefits since inflation will affect most prices in the same way, preserving the relative relationship between prices. The BCR was calculated using a discount rate of 12%, and the economic life of the BT was estimated to be 15 years by IDCOL and SNV. In Bangladesh, the data on discount rates is not uniform. As a result, a 12% rate was employed for analysis following the current literature (Kabir et al., 2012). We ran an NPV analysis before computing the BCR, taking into account the benefit-cost analysis estimation's temporal dynamics.

The economic benefits derived from LPG saving, traditional biomass consumption cost-saving, chemical fertilizer saving and, earning revenue from the carbon credit scheme reducing CO₂eq emission yearly. The initial investment cost, as well as operations and maintenance expenditures, are incurred for the domestic BT. The BCR can be expressed as:

$$\text{Benefit-Cost Ratio} = \frac{\sum_{t=1}^n \frac{B_t}{(1+i)^t}}{\sum_{t=1}^n \frac{C_t}{(1+i)^t}} \quad (7)$$

Source: (Abbas et al., 2017; Gabisa and Gheewala, 2019): pp.451, 433

Where: B_t = Yearly benefit; C_t = Yearly cost; i = Rate of interest, n = Number of years.

2.6.2 Net Present Value (NPV), Payback Period (PBP)

The terms NPV and PBP are commonly used to assess a project's economic viability. The NPV is used to determine if a project is profitable or not; if the NPV is positive, the project is economically viable.

$$NPV = \left[\sum_{t=1}^n \frac{CF_t}{(1+i)^t} \right] - I_0 \quad \text{or} \quad NPV = \left[\sum_{t=1}^n \frac{TAB_b - AOT_c}{(1+i)^t} \right] - I_0 \quad (8)$$

Source: (Kabir et al., 2012)

Where, CF_t = Cash flow in year t ; TAB_b = Annual benefits; AOT_c = Annual operating costs; n = Project life time; i = Discount rate; and I_0 = Initial investment cost.

The payback period (PBP), which shows us how long it will take to return the initial investment cost, is another economic indicator used to measure the project's economic viability.

$$PBP = \frac{\text{Initial Investment}}{\text{Annual Operational Cash Flow}} \quad (9)$$

Source: (Gabisa and Gheewala, 2019): pp. 451

3. Results and Discussion

The study's findings revealed that a small-scale domestic anaerobic cow dung biogas digester can reduce carbon emissions by around 7.8 tons of CO_2 equivalents in a year. It also showed that doing so is economically feasible since both the NPV and BCR were positive. The detail of GHG emissions reduction and the economic analysis of the study is discussed in the results and discussion part.

3.1 GHG Emissions, and Mitigation

3.1.1 GHG (Methane) Emission from Cow Dung Management

Cow dung produces the most potent global warming GHG is methane (CH_4). And the technology can successfully reduce the emission of methane from cow dung in the open pit by transforming it as a raw material into biogas digesters. A common size of small-scale biogas digester (2.4 m^3) required at least four cows which can generate on an average 1.2 m^3 biogas daily (IRENA, 2016; Khan and Martin, 2016).

Thus, the average annual methane emissions from the 2.4 m^3 biogas digesters were 4599 kg CO_2eq in the considered areas, which is currently avoided by regulating the manures in the digester. Another source of methane emission is leakage during the biogas generation phase, and the fixed dome digester's methane collection efficiency is 0.975. A total of 117.918 kg of methane was estimated to have spilled from the digester and therefore, 8.254 tons of methane were being leaked from the 70 digesters. However, the biogas plant reduces on average 4.48 tons of CO_2e per year. This can be the most compelling argument for the highest GHG emissions from the technical use of cow manure, which are mitigated by BT.

3.1.2 GHG Emissions from Chemical Fertilizer Application in Cropland

The household biogas digester with 4 cattle can produce 4230 kg dung (dry weight) per annum (Table 3). The biogas digester generates annually 1692 kg carbon (C) of bio-slurry [C content in slurry (kg kg^{-1} dry wt.) is 0.4, (i.e. 1692)] which substitutes 59 kg N, 42 kg phosphorus (P), and 33 kg potassium (K) fertilizer respectively, was calculated based on N content in slurry (kg kg^{-1} dry wt.), P content in slurry (kg kg^{-1} dry wt.), K content in slurry (kg kg^{-1} dry wt.) are 0.014, 0.01 and 0.008 respectively. The production of these chemical fertilizers has GWP which is 214.74 kg $\text{CO}_2\text{eqv.}$, where CO_2 emission for N, P, K fertilizer production (kg kg^{-1}) are 1.3, 0.2, 0.2 respectively and N_2O -N emission from N fertilizer application (kg kg^{-1}) is 0.007. Table 3 shows the global warming potential estimates for several sources that were used to calculate the decrease of GHGs emission reduction from a family-sized cow dung BT (Pathak et al., 2009).

Table 3. Coefficients used for calculation of GHG emission potential of a household biogas plant

Parameter	Conversion factor	Reference
Average annual cow dung production per cattle (kg dry wt.) ^{a,b}	4230	Author's calculation
Methane content in biogas (%)	60%	(Pathak et al., 2009)
C content in slurry (kg kg ⁻¹ dry wt.)	0.4	
N content in slurry (kg kg ⁻¹ dry wt.)	0.014	
P content in slurry (kg kg ⁻¹ dry wt.)	0.01	
K content in slurry (kg kg ⁻¹ dry wt.)	0.008	
CO ₂ emission for N fertilizer production (kg kg ⁻¹)	1.3	
CO ₂ emission for P fertilizer production (kg kg ⁻¹)	0.2	
CO ₂ emission for K fertilizer production (kg kg ⁻¹)	0.2	
N ₂ O-N emission from N fertilizer application (kg kg ⁻¹)	0.007	
GWP of CO ₂ (kg CO ₂ eqv. kg ⁻¹)	1	(IPCC, 2007)
GWP of CH ₄ (kg CO ₂ eqv. kg ⁻¹)	25	
GWP of N ₂ O (kg CO ₂ eqv. kg ⁻¹)	298	

Note. ^aCow dung productions (dry wt.) per cattle and buffalo are 1,100 and 1,350 kg year⁻¹, respectively (Gaur);

^bCow dung lost during collection (30%) and used for construction (1–9%) was deducted from total production (TERI, 2001).

Bio-slurry is utilized as a fertilizer on agricultural farmland in the studied site. In comparison to non-user households, biogas-user households (87 percent) stated that about half of the total purchase of chemical fertilizer is turned over using bio-slurry in the specified production year, whereas biogas-users could reduce about 50% fertilizer usage by using bio-slurry in China (Ding et al., 2012). There are few reports that bio-slurry cannot replenish nutrients to grow plants without using chemical fertilizers. Hence, the user households could have reduced at the minimum half of the fertilizer usage by proper utilization of bio-slurry. This, in succession, could have relieved the biogas-users mostly from purchasing overpriced chemical fertilizers and additionally reduced GHG emission by 15.03 tons of CO₂eq (Uma, 2014).

The application of bio-slurry as a fertilizer boosts soil fertility by enhancing nutrient contents. The producing amounts of bio-slurry are varied with different digesters sizes. A correctly used domestic biogas can generate an average of 2.6 tons to 3.5 tons of solid bio-fertilizer yearly (Mengistu et al., 2016). In the study, the average bio-slurry from (2.4 m³) biogas digester is 1.6 tons which provides 59 kg of Urea per annum. As a result, the GWP for manufacturing similar amounts of chemical N, P, and K fertilizer is 15.031 tons CO₂eqv. for the complete sample of biogas-user households. Furthermore, bio-slurry provides accessible plant nutrients faster than fresh manure. In addition, both major and micronutrients are present in bio-slurry and are essential for plant growth (Barbosa et al., 2014). Unfortunately, the farmers used it without proper knowledge about managing and using slurry.

3.1.3 CO₂ Emissions from Biomass Combustion and LPG as Fuel

The main problem of rural areas is traditional biomass is burned directly for cooking which usually segregates CO₂ in the atmosphere. Firewood, residue, and cow dung are the primary source of energy for cooking in the considered areas. The utilization of biogas energy is capable to decrease conventional biomass and non-renewable fuel consumption, and in turn, emissions of GHGs. Using equations 4 and 5, the amount of fuel consumption was calculated by taking the carbon emission factors of 0.45, 0.4, and 0.24 for firewood, dung, and LPG respectively (Pei-dong et al., 2007; Shane and Gheewala, 2017). The average GHG emissions from using firewood, cow dung, residue, and LPG was 122.48 tons, 47.33 tons, 50.22 tons, and 0.963 tons of CO₂eq respectively, which were estimated considering the replacement proportion of biomass fuels with the biogas produced by the 70 digesters, and thus the total amount was 221 tons CO₂eq (Figure 1).

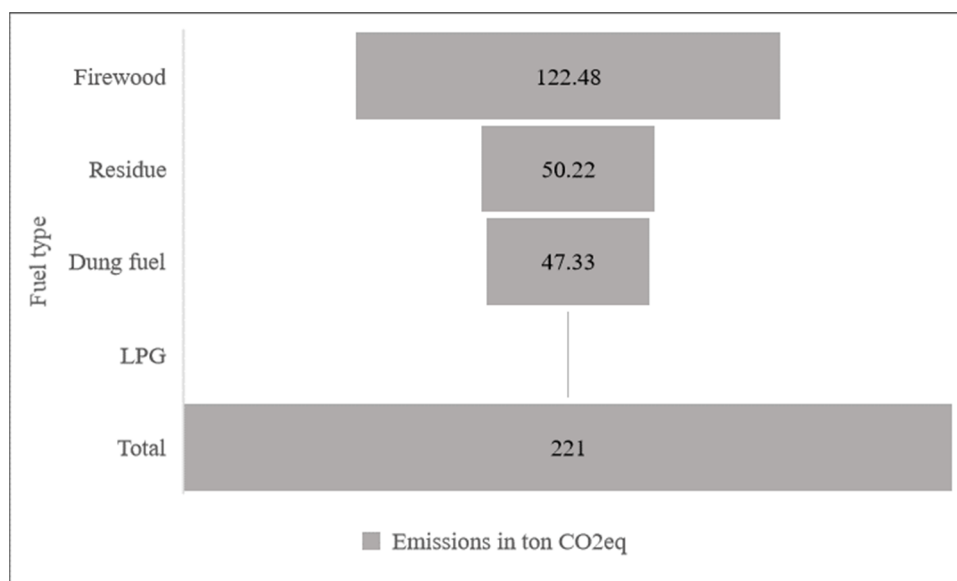


Figure 1. Average GHG emissions per year in ton CO₂eq from various fuels utilized by biogas-users

The use of biogas energy instead of traditional biomass fuels alone reduces GHG emissions on average of 3.1 tons of CO₂e yearly. The obtained value is lower than the findings of Katuwal and Bohara (2009) (4.5 ton), Laramée and Davis (2013) (6.4 ton), and Pathak et al. (2009) (9.7 ton) but higher than that of Zhang et al. (2013) (1.3 ton). The justification for these dissimilarities could be the absence of country-specific emission factors. The other explanation could be linked to the building materials required for biogas start-up as well as the current state of fuel consumption. Notable that, maximum households had used remaining cow dung in cropland and that dung was stored in a pit whereas it emitted GHG regularly is avoided because there are no available measurement materials in our country.

Furthermore, in addition to reducing GHG emissions from cooking fuel, users were asked about the social welfare attained as a result of the BT introduction vs their previous experience during the survey. They replied that BT improves health conditions by reducing smoke in the kitchen since it takes the place of a typical stove for cooking. Therefore, it could reduce eye or respiratory diseases as well as reduce indoor air pollution.

Biogas energy helps the turndown of woody biomass by replacing the consumption of wood fuel and other household energy sources. A small-scale biogas plant reduces 1217.83 kg of wood fuel per year. Therefore, the annual potentiality of wood fuel replacement of entire sample biogas digesters is 85.24 tons which indirectly can save the country from deforestation.

3.1.4 Life Cycle of GHG Emission Reduction

The GHG emission reduction owing to the use of BT in the studied areas was calculated using equation (6).

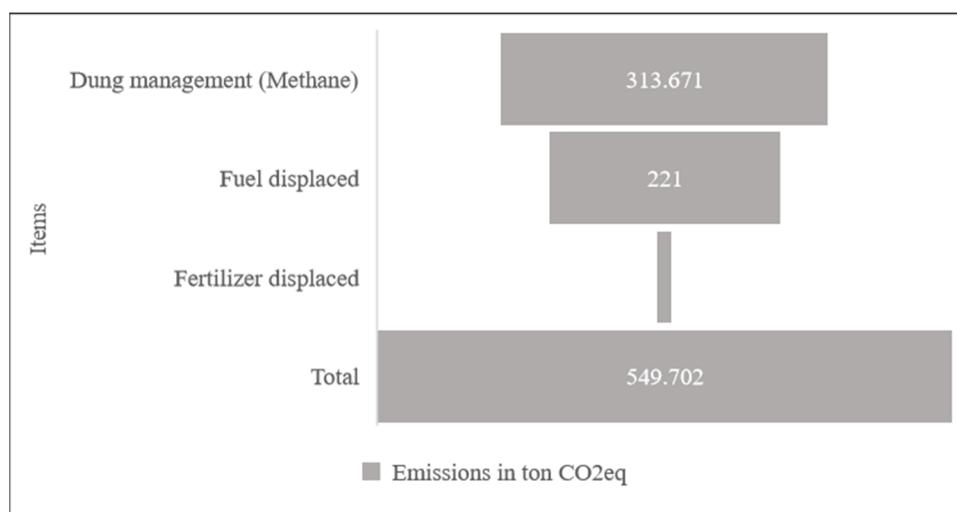


Figure 2. Average annual GHG emissions in ton CO₂eq from total (70) sample biogas plant

The amount of cow dung management and the displacement of chemical fertilizer and fuel were all factors in the calculation of GHG emissions. The methane emitted as a result of leakage during anaerobic digestion is not credited; rather, it is deducted as emission from the system. About 549.702 tons of CO₂e has been reduced annually from 70 biogas digesters (Figure 2). Therefore, the small-scale biogas plant mitigated 7.8 tons of CO₂e annually in the studied sites.

3.1.5 Potentiality of GHG Mitigation in Bangladesh

There are different biogas digesters established in Bangladesh ranging from 2.0 m³ to 4.8 m³. The daily rated biogas production capacity is different for each of them. According to IRENA (2016), a 2.0 m³, 2.4 m³, 3.2 m³, and 4.8 m³ biogas digester can produce 0.7 m³, 1.2 m³, 2.8 m³, and 9.65 m³ biogas per day respectively. So, it is estimated that 2.0 m³, 3.2 m³, and 4.8 m³ biogas digester can reduce 4.8 tons, 17.1 tons, and 61.2 tons CO₂e per annum respectively.

Table 4. Average annual GHG emissions in ton CO₂eq from different sizes of the biogas digester

Items	Biogas Digester			
	2.0 m ³	2.4 m ³	3.2 m ³	4.8 m ³
Cow dung management (Methane)	2.6	4.48	10.456	35.036
Chemical fertilizer displaced	0.077	0.214	0.375	0.75
Fuel displaced	2.14	3.1	6.27	25.38
Total	4.82	7.8	17.1	61.2

According to a report by IDCOL (there, 100000 domestic biogas plants are running in Bangladesh. As 7.8 tons CO₂e is reduced by a single digester per annum, it is estimated that an annual average of 78000 tons CO₂e is mitigating by domestic BT in Bangladesh. Therefore, Bangladesh can contribute to reducing global warming to a large extent by increasing the domestic biogas users through over the country.

3.2 Economic Analysis

3.2.1 Benefit-cost Analysis

A BCR was calculated for BT plants at the three distinct levels of usefulness; benefits of fuel replacement, fertilizer substitution, and carbon trading. Considering the energy mix of the studied areas, a 2.4 m³ biogas digester can replace 1217.83 kg of wood fuel, 541.88 kg of cow dung, and 589.71 kg of residues in a year. We have done the NPV analysis of the decision on investing in the biogas plant that considers the costs of digester construction, expenditure on biomass, and the procurement cost of fertilizer. Other potential benefits of bio-digester installation,

such as increased farm income, health improvements, and surplus time were not included in the analysis.

Table 5. Cost-benefit analysis of small-scale biogas plants

Items	Biogas digester (2.4 m ³)
Average investment cost	36032
Average annual current cost	
• Depreciation cost	1441
• Cow dung cost	2890.8
• Maintenance cost	1441
Total cost	5772.8
Average annual current benefits	
• Fuel replacement	13023
• Chemical fertilizers displaced	3085
Total benefits	16108
BCR	1.74
NPV	50128.44
PBP (year)	2.53

Note. All the units of the benefits and costs are in Bangladeshi taka (BDT). The currency conversion rate was considered (1USD~84 BDT) as in the year 2019. Maintenance and depreciation costs account for 4% of investment costs.

The economics of a biogas plant is characterized by a high investment cost, some operating and maintenance costs, mostly free raw materials, income generation from gas production, and earning foreign currency. The investment costs covered the major part of the total cost of a biogas plant. The average investment cost of the household biogas plant (total volume 3 m³) was BDT 36032. It is also estimated that the average investment cost of a small-scale biogas plant in study areas was about USD 428.9 (1 USD=84 BDT) while for Pakistan, Nepal, Vietnam, China, Rwanda, Tanzania, and Kenya was estimated to be 426, 547,480, 293, 1306, 780 and 787 USD, respectively (Von Eije, 2012).

The findings estimated BCR with the discount rate of 12%, interest paid to the NGOs at 8% for up to 24 installments monthly, and a lifespan of 15 years for a plant. Similarly, Von Eije (2012) and Haque (2013) used the duration of constructed biogas digesters of up to 15 years in Bangladesh where and Walekhwa et al. (2009) considered the duration of a biogas plant to be 20 years in India and Uganda. The lifespan of a biogas plant often varies with construction materials, weather, soil structure, input uses, etc. The BCR of the 2.4 m³ biogas digester was 1.74 (Table 5), showing that the plant is cost-effective and provides sufficient advantages to cover expenditures which indicates that the biogas plant is financially viable. (Gabisa and Gheewala (2019)) estimated BCR which was 1.8 for 8 m³ biogas plants in Ethiopia. This variation occurred due to the size of the biogas plant, the price of cooking fuel and chemical fertilizer, and other operating and maintenance costs.

3.2.2 Estimation of economic evaluation

The CDM is one of the flexible mechanisms defined in the Kyoto Protocol (IPCC, 2007) that provides for emissions reduction projects which generate certified emission reduction (CER) units that may be traded in emissions trading schemes. Bangladesh has succeeded very little in accruing CDM benefits. It lacked robust institutional mechanisms to submit emissions reduction projects to the UNFCCC in generating CER. Due to the volatility in price linked with the recent global economic recession, the carbon market is yet to reap the benefit of CDM projects. It has been estimated in this study that a small-sized biogas plant can reduce on an average 7.8 tons CO₂ emission, and would earn 6300 BDT per year, with the price of reduction charged at USD 10 per ton CO₂eq according to the World Bank's State and Trends of Carbon Pricing 2018 (World Bank, 2018).

Table 6. NPV, BCR, and PBP of a small-scale biogas plant under carbon trading

Items	Biogas digester (2.4 m ³)
NPV (BDT)	62121.71
BCR	1.9
PBP (year)	2

The NPV, BCR, and PBP of a biogas plant with carbon trading were BDT 62121.71, 1.9, and 2 years respectively (Table 6), which indicates that adding carbon emission price in total benefits is economically viable for the society. Katuwal and Bohara (2009) also provided a successful economic benefit to the country through reduced deforestation and carbon trading. Even, Adeoti et al. (2000) showed that the 6.0 m³ family-sized biogas project using cow dung as a substrate in Nigeria has good economic potential. However, Haryanto et al. (2017) reported that a family-scale biogas digester using cow dung in Indonesia demonstrated a lot of promise for reducing GHG emission, but it was not economical. This difference from various factors that affect results such as production capacity of biogas, the potential use of biogas, economic condition, measurement unit, etc.

However, our overall findings expressed that the biogas plant is a cost-effective and economically viable technology. Most people could easily adapt to this technology and gained more facilities from the biogas plant.

3.2.3 Sensitivity Analysis

Sensitivity analysis is a method for determining how sensitive an analysis' conclusions are to the assumptions used; that is, whether or not the results change significantly when the assumptions are changed. For example, the discount rate's value, the assumption of steady fixed relative prices, life span, and so on. A sensitivity study was conducted for this project, which included a 10% increase in expenses and a 10% drop in benefits. A 10% increase in costs and a 10% reduction in benefits is based on the assumption that benefits may be reduced by 10% in the future due to any change, such as an increase in capital costs due to inflation, the implementation of new taxes by the government, an increase in daily labor wages and/or an increase in supply or any other input costs, and so on. It may differ from one field to the next and from one analysis to another. Furthermore, we want to see if such an increment will sustain a positive BCR. Just to keep a cushion for any such change (if occurs) and to sensitize the estimation.

Table 7. Sensitivity analysis of BCR of biogas plants

Assumptions	Analysis	NPV (BDT)	BCR	PBP (year)
Life span 10 years	Financial	19299.57	1.28	3.19
Discount rate 12%				
10% rise in cost	Economic	28345.80	1.41	2.94
10% rise in benefits				
Life span 15 years	Financial	31630.98	1.42	3.19
Discount rate 12%				
10% rise in cost	Economic	42424.93	1.57	2.94
10% rise in benefits				
Life span 15 years	Financial	8800.25	1.14	3.4
Discount rate 20%				
10% rise in cost	Economic	15774.65	1.24	3.5
10% rise in benefits				

Table 7 demonstrates that the BCR values for all assumptions are still larger than 1. Biogas plants' BCR varies, indicating that they will be able to generate enough benefits to pay costs even if their costs rise and their benefits fall. In addition, the values of NPV, and PBP state that the biogas plant is still not only financially but also

economically viable.

4. Conclusions

The biogas plant technology is an alternate energy source that can play a major role in reducing GHG emissions by substituting fresh cow dung, cooking fuel, and chemical fertilizer. The replacement of traditional biomass fuels with biogas energy reduces on average 3.1 tons of CO₂e. This study also assists in calculating the GHG emission from LPG burning and chemical fertilizer use in croplands. The bio-slurry substitutes 59 kg of N, 42 kg of P, and 33 kg of K fertilizer, respectively per annum, which produces 214.73 kg CO₂e per digester. When compared to conventional manure, bio-slurry provides better quality fertilizer in terms of least accessible nitrogen fertilizer. It provides more nutrients to the soil and can save the soil from erosion. The economic aspects of the biogas technology in the studied sites are also discussed. The biogas system's NPV, BCR, and PBP have been studied. The values were positive that indicated that small-scale biogas plant is not only environmental friendly but also economically viable technology. With proper management and performance of a large number of existing and potential biogas plants, Bangladesh has a good opportunity to solve its energy crisis, reduce global warming and earn substantial revenue under the new regime of carbon marketing.

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