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Research article

Financial and functionality analysis of a biogas plant in Bangladesh

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ABSTRACT

Installation of a biogas plant in a rural region has become a viable alternative energy source with a variety of health and environmental advantages. Though Bangladesh has enormous resources for biogas production, biogas energy production is infancy stage in Bangladesh. The study aims to explore the economic aspect of household-level biogas plants and determine the relationship between biogas plant functionality and different factors. For doing this, 300 biogas plant owners were interviewed from fifteen Upazilla in Bangladesh and respondents were chosen by a two-stage random sampling technique. The study shows by measuring partial budgeting, USD 294.80 per year can be earned by a family by introducing biogas plant. Cost-benefit analysis showed that a small biogas plant (USD 143.07/year) was most profitable, followed by a large biogas plant (USD 142.17/year). In discounted cost-benefit analysis, medium size biogas plant was found to be the most beneficial investment, followed by a small size biogas plant. Average NPV, BCR, PBP, and IRR of Biogas plant were USD 1629.11, 1.77, 2.93, and 48% with subsidy where USD 1525.25, 1.77, 3.75, and 43% without subsidy. The measurement of carbon trading also highlights the economic benefit of a biogas plant in Bangladesh. The bivariate relationship between the functionality of biogas plants with different factors highlights that higher educated, trained plant owners with quality mason and follow up services ensured the efficient operation of the biogas plant.

1. Introduction

Bangladesh depended on indigenous natural gas for its power generation having huge availability in the country's reserve. Almost 89 percent of Bangladesh's required power is generated from natural gas, and the rest comes from coal, liquid fuel and hydropower. The renewable energy source provided only 2.5 percent of the total energy requirement (MPEMR, 2014; SREDA, 2018). Currently, nearly 16% of world energy comes from renewable and nuclear power, while the rest of 84 percent comes from fossil fuels (Ritchie and Roser, 2019). This major fossil fuel use causes ecological and environmental problems worldwide (Karekezi, 2002). Bangladesh is currently investigating renewable energy sources, particularly solar panels and biogas plants (Rana et al., 2021a). As an agriculture-based country, Bangladesh has enormous potential for implementing biogas technologies. Currently, Bangladesh has nearly 100,000 biogas plants and more than 58,000 plants are financed and monitored by Infrastructure Development Company Limited (IDCOL, 2021). According to the IFRD, Bangladesh has a potential for roughly four million biogas plants (BPDB, 2010). However, a household will seek assurance of a cheap and reliable supply of raw material before adopting a biogas plant. In a Biogas plant, many potentials raw materials can be used for energy production like animal, human waste, crop, household and industrial waste. Due to the technological limitation in Bangladesh, a household can use only cow dung as a major feedstock for the biogas plant.

Biogas technology is not very complex but rather quite simple, easy to operate, and therefore, acceptable to common people. Besides, raw materials can be made easily available and are also relatively cheap, economical, and affordable. Biogas has a different aspect of economic benefits, it provides gas, electricity and fertilizer to the household. However, the cost of digesters has been the most significant limitation in biogas operations. Because of the decline in subsidies, new biogas plants, each year have decreased substantially, leading to the movement from Biogas to coal (Qiu et al., 1990). Poor backup services might also be blamed for the poor performance of previous biogas digesters. Widespread poor performance of biogas plants also resulted in the relatively

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high adoption rate breakdown (Kristoferson and Bokhalders, 1991). Previously renewable energy was treated as economically unviable (Rowlands et al., 2003; Rana et al., 2021b). It has nonetheless been deemed technologically and economically feasible in light of the full package of economic and environmental benefits (Bahauddin and Salahuddin, 2012). With existing biogas production and utilization incentives, households need to evaluate whether a valuable investment exists in biogas technology. But, they need to have accurate feasibility information about biogas energy production and its potential utilization before making any rational decision. Households should have information on whether adopting biogas plants will increase or decrease the future family income.

This study aims to assess the economic viability of smallscale biogas plants considering all the advantages and costs associated with the biogas plant in Bangladesh. Household need to estimate the sustainability of biogas plant's production and utilization and compare it with other alternative resources having available resources. The operating level at which the biogas system can continue to function profitably is another important goal of this objective. The relationship between different parameters and the operation of the biogas plant will also be covered in this study. The assuredness of biogas plant operations is one of the main barriers. Many owners ended their plant operations because of lacking training, and knowledge. Even if a biogas plant is perfectly built and constructed, it will not perform efficiently if operated incorrectly. Poor operation and maintenance could lead to the collapse of the plant. Our study tried to find a relationship between the biogas plant functioning and different factors like household characteristics, training, and regular service. We hope our study will provide first-hand knowledge to potential biogas users about biogas plants' benefits, cost, and functionality. This study will also help the policymaker to take target-based measures for a mass installing a biogas plant in Bangladesh.

2. Methodology

A combination of the qualitative and quantitative methods used for this study. Different approaches like interviews of key stakeholders, focused group discussion and a survey questionnaire conducted for the study's purpose.

2.1. Population and sampling procedure

The study was conducted in 15 Upazillas having the highest concentration of biogas plants and selected purposively. These areas were also selected by discussing with the NGOs. These Upazillas are Dhaka, Srepur, Gazipur Sadar, Sonargaon, Naryanganj Sadar, Haluaghat, Atghoria, Pabna Sadar, Sadullapur, Kalai, Sadar Khustia, Godagari, Rajshahi, Khagrachari Sadar. All the biogas plant owners were considered as the population for this study in these 15 districts. The sample size (n) was taken by adopting the Cochran (1963) equation which is widely used by authors (Saha et al., 2022; Hossain et al., 2022) on conditions that estimated sample will yield 95% precision on the statistical interference.

$$n = p(1-p)\left(\frac{Z}{e}\right)^2 \quad (1)$$

where,

N = Sample Size
z = The desired confidence level (95%)
p = The percentage of an attributes in population.
e = Precision level

The sample size (n) varies depending on the likely value of precision level (e). We solved the above Eq. (1) for a 5% precision rate and found our sample household size 300.

2.2. Data collection

Data were collected from the head of the household by using the survey technique. Before collecting data, two focused group discussions were held, and questionnaires were checked from the result of FGD. Each FGD group consisted of 10 members (5 Male households, 3 Female households, 2 NGO representatives) held in Srepur and Rajshahi Sadar Upazila. Besides, a pilot study was conducted for finalizing the questionnaire. Finally, well-structured interview schedules were designed for study purposes. We used two stages random sampling method for interviewing 300 biogas plant owners. We have selected small-scale biogas plants in the study area for our study purpose. There are three types of small-size biogas plants that are operated in Bangladesh that are 2.4 m^3, 3.2 $m^{3,}$ and 4.8 m^3 capacity plants.

2.3. Financial analysis of biogas plant at the household level

2.3.1. Partial budgeting of a biogas plant

The partial budgeting technique is used as decision-making framework for a creative household weighing benefit and cost analysis of many possibilities. In this framework, a household can evaluate the economic effect of minor or major adjustments in some portion of the adoption of technology. It calculates the change in net project income from a specific action. Partial budgeting has four essential parts – increased income, increased cost, reduced income, and reduced costs (Dalsted, 2008).

It benefits by adding income and reducing cost where it incurred loss by adding cost and reducing income. For biogas plant, added income come from saving time and value-added from bio-slurry. Added costs consist of construction costs, labour costs, cow dung, and interest and maintenance costs. Cost reductions come from fewer illnesses, less traditional fuel use, and less use of chemical fertilizers, among other things. In addition, no activities were found that could reduce the income for using biogas plants. Briefly stated, partial budgeting analysis helps the farm owner to understand how their decision will impact the income of the business. . In doing partial budgeting analysis, we have asked households about the time they used to collect fuel for their daily activities, reduction of their medicine cost, amount of biofertilizer used in the field, and cost of operating biogas plant. We then convert the whole activities within the monetary term. We used the average result of all the biogas plants regarding the size to present our findings in the result section.

2.3.2. Current costs and benefit analysis of small-scale biogas plant

Adopting small biogas plants largely depends on household cost-benefit scenarios (Srinivasan, 2008). The project may have wider implications for reducing environmental degradation, poverty alleviation, and employment generation – but if these do not affect the firm's profit, investors are omitted from the analysis (Campbell and Brown, 2003; Kamruzzaman et al., 2021). A private project may receive a subsidy, pay tax or provide employment and reduce pollution.

In this study, the biogas plant's financial estimation of the biogas plant was as calculated based on four situations: without subsidy, with subsidy, reduction in maintaining health costs, revenue-generating concern. Here, without subsidy, no government or NGOs incentives were considered in the financial analysis. Besides, discounted costs and benefits were analyzed by doing adjusted with the inflation rate & growth rate of wages.

2.4. Estimation of financial evaluation

Following the quantification and appraisal of biogas technology, we apply net present value, internal rate of returns, benefit-cost ratio and payback period for financial analysis.

2.4.1. Net present value (NPV)

According to Von Eije (2012), the economic lifespan of fixed dome biogas plants is up to 15 years. However, many other studies suggest the biogas dome can operate for up to 20 years (Walekhwa et al., 2009; Kandpal et al., 1991; Biswas and Lucas, 1997; Rubab and Kandpal, 1995, Adeoti et al., 2000). Indeed, IDCOL and SNV estimated that the small-scale biogas digestor could be operated for 15 years.

The below equation widely used by different authors where they considered the initial investment cost I_0 negative (Torries, 1998; Brigham and Ehrhardt, 2011):

$$NPV = \left[\sum_{t=1}^{n} \frac{CF_t}{(1+t)^t}\right] - I_0 \tag{2}$$

In Eq. (2), CF_t represents cash flow in year t, I represent discount rate, n represents total years, and I_0 represents initial investment cost. The acceptance of a project largely depends on *NPV* value, and positive *NPV* value will lead to the adoption of the project from the economic and financial points of view. A private investor will not accept a project which yields a negative *NPV* value. However, from an economic point of view, several factors would be considered to have a rational decision regarding the adoption.

2.4.2. Internal rate of return (IRR)

According to Torries (1998) and Belli et al. (2001), IRR is a financial tool broadly used to estimate interest rate, which makes the present value revenue equal to zero. It can be expressed following way;

$$NPV = o = \left[\sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t}\right] - I_o \tag{3}$$

In Eq. (3), IRR is the internal rate of return, CF_t represents the cash followed at year t, and I_0 represents the initial investment cost. The private investor will adopt the project if the IRR is higher than the opportunity cost of capital (Drury, 2008).

2.4.3. Payback period (PBP)

The payback period (PBP) is the amount of years a project would need to recoup its initial investment cost through annual net cash revenues (Groppelli and Nikbakht, 2006; Balakrishnan et al., 2009; Hansen and Mowen, 2009). Drury (2008) determined by adding up the predicted cash flow in subsequent years until the total cost equaled the initial outlay. It can be expressed through the following equation:

$$\text{Discounted payback period} = \frac{A+B}{C}. \tag{4}$$

In Eq. (4), A refers to the discounted cash flow in recent years, and B denotes the discounted cash flow at the end of period A, whereas C signifies the following year discounted cash flow. Private investors normally prefer short PBP. In this study, we calculated the annual net revenue using the projected growth rate, inflation, exchange rate, and wage index (For details, additional Tables 1, 2, 3, 4, 5, and 6). A short PBP is more preferable for economic activity. This study calculates annual net revenue considering the projected inflation growth rate, wage index, and exchange rate. We did not assume an equal and undiscounted payback period because a constant rate does not provide actual computations where annual benefits and annual operating costs are not uniform over the projects lifespan.

2.4.4. Benefit Cost Ratio (BCR)

Benefit-Cost analysis is a financial estimator used by the investor to assess the project feasibility (Rana et al., 2021a).

The BCR formula is as follows:

$$BCR = \frac{\sum_{t=1}^{t=T} \frac{(Benefit_t)}{(1+r)^t}}{\sum_{t=1}^{t=T} \frac{(cost_t)}{(1+r)^t}} \tag{5}$$

From Eq. (5), *BCR* is calculated by dividing revenue's present value by its cost. A project is said to be feasible if *BCR* is greater than 1.

2.5. Estimation of economic evaluation on carbon trading

Along with financial gain from the biogas plant, it also provides positive externalities to society by reducing NO, CO_2 and CH_4 emissions contributing to the shortening of global warming (Lovrencec, 2010).

Currently, the emission reduction credits are between $5 and $7 per ton in carbon markets, and according to the expert, the price should remain below $10 per ton of carbon dioxide for the next few years (Gofran, 2012). Grameen Shakti has been working on constructing 15, 000 biogas plants since 2006 in Bangladesh (Grameen Shakti, 2012). In this study, according to IDCOL, small scale biogas plant could reduce emissions by 2.5, 3.0 and 4 tons of CO_2 for 2.4 m^3, 3.2 m^3, and 4.8 m^3 capacity plants, respectively.

2.6. Bivariate relationship analysis between biogas operational status and demographic characteristics of the owner

In this section, we studied the factors responsible for the non-functioning of the biogas plant. Chi-Square is an inferential statistics or significance testing tool. It tests the significance of association shown in contingency tables (Cross-tabulations) in this context. Any pattern in this study's association found in a Crosstab is usually a pattern in Sample Data. Chi-Square is used when determining if a relationship in a sample of data is significant enough to support drawing conclusions about a wider population. Chi-Square approaches this problem primarily by comparing the Observation. Data Frequencies of each cell with their corresponding Expected/Fit Values computed from the data under the assumption (null hypothesis) that there is no relationship between the two variables in question. If there are large differences between Data and Fit, we will get a larger Chi-Square value and are more likely to find a "significant" association. The precise calculation of Chi-Square (c^2) is given by:

$$C^2 = S\ (\text{Observed Frequency} - \text{Expected Frequency})^2/\text{Expected Frequency} \tag{6}$$

However, for this study, the Pearson Chi-Square is the only Chi-Square value that matters which will be calculated using Eq. (6). The

Table 1. Partial budgeting of a biogas plant.

Added income (USD/year) (i)		Added cost (USD/Year) (ii)	
Savings of time	169.38	Labor	121.88
Bio-slurry	126.70	Depreciation cost	18.27
		Interest	24.70
		Cow dung	70.65
		Maintenance cost	18.27
Reduced cost (USD/year) (iii)		Reduced income (USD/year) (iv)	
Disease	9.80		
Alternative fuels	204.52	None	
Alternative fertilizers	38.19		
Sub-total (v) = (i) + (iii)	548.60	Sub-total (vi) = (ii) + (iv)	253.78
Net change (USD/year):	548.60–253.78 = 294.82		

Table 2. Estimation of annual current costs for small scale biogas plants.

Name of the components	Biogas plant capacity			Mean
	Small	Medium	Large	
Cow dung applied (kg/day)	63	89	119	90.33
Cow dung cost (USD/year)	49.27	69.61	93.07	70.65
Labour cost (USD/year)	84.38	93.75	187.5	121.87
Maintenance cost excluding labor cost (USD/year)	15.62	18.10	21.05	18.26
Miscellaneous cost excluding labor cost (USD/year)	15.62	18.10	21.05	18.27
Total cost (USD/year)	164.93	199.58	322.69	229.06

Table 3. Estimation of annual current benefits of biogas plants (USD/year).

Items	Biogas plan capacity			Average
	Small	Medium	Large	
Firewood	157.57	143.57	227.57	176.23
Agricultural residues	43.58	10	3.86	19.15
Dry dung cake	12.14	9.69	5.58	9.13
Reduced cost of chemical fertilizer	30.42	24.62	59.52	38.17
Slurry	64.30	147.45	14,141	126.70
Total benefit	308.02	335.33	464.86	369.40
Profit	143.08	135.76	142.19	140.34

Table 4. Estimation costs and benefits adjusted with inflation rate & growth rate of wage and discounted costs & benefits of a biogas plant.

Component	Small	Medium	Large	Mean
∑ Benefit	5046.85	5657.92	9307.04	6670.61
∑cost	2708.95	3275.76	5306.19	3763.63
∑Profit	2337.89	2382.15	4000.83	2906.96
∑Discounted Benefit	4506.11	5051.71	8309.84	5955.89
∑Discounted Cost	2436.38	2924.78	4737.67	3366.27
∑Discounted Profit	2087.40	2126.92	1731.88	1982.071

Table 5. NPV, IRR, PBP and BCR of different biogas plants with subsidy.

Name	NPV (USD)	IRR (%)	PBP (year)	BCR
Small plant	1798.63	53%	2.99	1.85
Medium plant	1776.13	48%	3.54	1.72
Large plant	1312.65	45%	2.27	1.75
Mean	1629.11	48%	2.93	1.77

Table 6. NPV, IRR, PBP and BCR of different biogas plant without subsidy.

Name	NPV (USD)	IRR (%)	PBP	BCR
Small plant	1696.26	45 %	3.73	1.84
Medium plant	1674.13	40 %	4.25	1.72
Large plant	1205.38	43 %	3.27	1.75
Mean	1525.25	43 %	3.75	1.77

interpretation of Chi-Square computing output entails examining the significance probability or corresponding P values – if this is less than 0.05, the correlation would be considered significant. If this is less than 0.05, the correlation would be considered significant. It would be interpreted as proof of the relationship between the different variables in the population from where the sample was developed.

2.6.1. Ethical approvement

The ethical standard of this research has been approved by the Ethical Review Committee (ERC) of the Research Management Committee (RMC) of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU). The information acquired for this study was treated with confidentiality. The survey was voluntary, anonymous, and the approval of every potential respondent was obtained before the interview.

3. Results and discussion

3.1. Partial budgeting of a biogas plant

An important policy-motivating approach to innovative business is a partial budgeting approach that can analyze all the components of costs and benefits of a given business for future planning. Partial budgeting has four essential features in two columns. A new business's positive and negative effects are calculated in the left and right columns, respectively (Tigner, 2006). Added income is typically estimated if the components of an innovative business have a chance to add such. The following Table 1 presents the saved time by biogas users normally employed for generating additional income. It has been observed that the savings in time are often utilized for home gardening, child care, poultry-livestock rearing, etc., to get additional income. Bio-slurry items also add a notable amount to annual income.

This study does not only consider the benefits of a couple of cost items. All associated cost items required for production purposes were calculated. The main added costs are the cost of labour, simple depreciation, interest on loans, cow dung, and operation and maintenance. The cost of cow dung is considered the greatest portion of added cost, followed by labour cost, interest on credit, depreciation, and operation and maintenance costs. Labor costs are generally viewed as an opportunity cost. As presented in Table 1, it is also recognized that costs on family health are reducing due to the adoption of the biogas system. Respiratory diseases and eye problems are mainly observed before biogas technology adoption, but households can save up to USD 9.80 per year on health expenses after adopting the technology. Kanagawa and Nakata (2007) and Acharya et al. (2005) also opined about reducing the health problem related to respiratory disease and eye problems. Traditional fuels like firewood, dry dung, and agricultural waste show radical savings - more than USD 204.52 per year. The study has not found any activities that involve reduced income due to constructing a biogas plant. Finally, net income from the project was positive at $294.82, suggesting the project will yield profit for the household. Barnes and Toman (2006) and Yiridoe et al. (2009) also find that small-scale biogas systems are economically feasible for the developing nation.

3.2. Current costs of a small-scale biogas plant

In this study, Biogas plant costs were calculated by adding capital, installation, and operating and maintenance costs. Most biogas plant costs are incurred to labour and civil construction costs. In this study, we categorized the biogas plant into three groups; Small (1.6–2.4 Cubic meters), medium (3.2 Cubic meters), and large (4.2 cubic meter) plants.

Thus, it could be assumed that the larger plants will require higher capital and operating cost (Table 2). We convert the dung amount into monetary value – 0.002USD/kg, following Singh and Sooch (2004). In normal practice, households take care of cattle for the continuous feedstock supply. However, the high price of cattle dung can hinder the operation of biogas plants if households decide to purchase cow dung for plants. In this study, labour cost has been calculated local market price (See appendix A2). The highest cost for operating a biogas plant was for the labour cost ($121.87), and the lowest cost was for the maintenance cost of the biogas plant ($18.26). Another study also concluded that labour and cow dung is the most dominant variable cost for the small-scale biogas plant (Kabir et al., 2012).

3.3. Current benefits of small-scale biogas plants

According to Singh and Sooch (2004) and Walekhwa et al. (2009), the advantages of a biogas plant can be calculated using the gas production capacity of the plants. However, it is impossible to measure the gas production capacity of biogas plants in Bangladesh due to the lack of installation gas measurement capacity meter. Thus, we used opportunity cost measurement to calculate biogas plants' benefits. As mentioned already, Biogas can completely eradicate the household's biomass fuel requirement. We calculated the household's total avoided biomass fuel cost as a benefit for the biogas plants. Table three shows the yearly cost of biomass fuel for household before installing the biogas plants.

Table 3 illustrates the benefit of biogas plants that were calculated from the biomass fuel, including firewood, agricultural residues, and dry dung cake. It also calculates reduced chemical costs as well as the sale price of slurry.

Table 3 shows that households can save an average $38.17 using the bio-slurry from the biogas plant instead of chemical fertilizer. A similar study in Pakistan found that bio-slurry can reduce 600 PKR per month cost of chemical fertilizer (Amjid et al., 2011). In Nepal, the researcher also found that bio-slurry can reduce the household dependence on imported chemical fertilizer and save up to $300 million nationally. In addition, it can support indigenous technology to growth (Ashden Awards, 2005; Gautam et al., 2009).It is evident from the study that biomass fuel cost reduction, slurry sale, and slurry used in crop fields generate significant benefits for the biogas user in Bangladesh. By comparison, large Biogas provided the highest benefit to the investor, followed by small and medium size plants. Data presented in Tables 2 and 3 showed that Biogas is a profitable investment for households, considering the associated cost and benefit.

3.4. Discounted costs and benefits of a small-scale biogas plant

In this section discounted rate is adjusted in different years in the life span of a biogas plant.

The various costs and benefits were also adjusted by the projected inflation rate (average increasing rate of 0.17 percent) and wage rate (average wage growth rate of 0.59 percent) on year to year basis (Details on the additional Tables 1, 2, 3, 4, 5, and 6). Table 4 shows the discounted benefits and costs during the life span of the biogas plant. Inflation rate measure based on Consumer Price Index and general inflation during FY 2001-02 to FY 2010-11 a, and Wage Rate Index from FY 2001-02 through FY 2009-10 (BBS, 2012).

The following section presents the assumption analysis with different aspects of financial and economic issues.

3.5. Estimation of financial evaluation

For financial evaluation, as mentioned earlier, we take into account the biogas plant's direct benefit and cost where we exclude the external benefit and cost.

3.5.1. With subsidy

In this study, we treated the base calculation for decision-making as the first assumption for the study. In this case, three categories are considered for calculation: small, medium, and large biogas users, with a discount rate of 12%, interest paid to NGOs at 8% for up to 24 monthly installments, and a plant lifespan of 15 years. Previously, authors like Von Eije (2012) and Haque (2008) used up to 15 years for constructing biogas digesters in Bangladesh, whereas Singh and Sooch (2004) and Walekhwa et al. (2009) calculated financial analysis using 20 years life span in India and Uganda respectively. Since 1992–93, GoB has sanctioned subsidy for the biogas users of USD 59.52 in 1993, USD 8928 in 1998 and USD 107.14 in 2006 (Haque, 2008).

According to the definition of NPV, if the value is positive (more than zero), the business should be continued in the future. In the study, The NPV value for biogas plants user in Bangladesh showed notable positive signs as a general trend. Table 5 shows that the estimated NPV for small, medium and large biogas users is mostly similar and comparable to Von Eije (2012) findings, who illustrate that the average NPV in Bangladesh is around 500 Euro for Biogas plants.

The study also shows that the average IRR for biogas plants is 48%, which is also higher than the discount rate. The findings align with the study of Von Eije (2012), who found that IRR for biogas plants is 45% in Bangladesh. Biogas users have receipts less than the total cost of biogas plants for less than three years for all categories, which is similar to Von Eije (2012) results.

The table also revealed that the mean BCR was 1.77. a similar type of study on Ghana on large size biogas plant conducted by Mohammed et al. (2017) found IRR 47% and BCR 5.19.

Finally, the study showed that small-scale biogas plants are most financially viable for households, followed by medium and large-scale biogas plants under subsidy assumptions. Therefore, it will be prudent for the household to adopt small-scale biogas plants if the current subsidy remains in Bangladesh.

3.5.2. Without subsidy

Bangladesh is an underdeveloped country where the continuation of subsidies might not be possible due to scarce internal resources and continuous pressure from donor agencies. GoB could withdraw the existing subsidy facility from the biogas arena after reaching a sustainable position. Hence, a person should have considered subsidy withdrawal to estimate the future investment of biogas expansion in Bangladesh. Table 6 shows the result of different financial instruments for the different groups of biogas users in Bangladesh.

Table 6 shows that households can earn $1525.25 from the biogas plants in Bangladesh on average. Small-scale biogas plants owner earns more than the medium size biogas plant owner, who also earn more than the largescale biogas plant owner. Besides, the average IRR for biogas plants was found 43% in Bangladesh, which is much higher than the 2% discount rate. . Von Eije (2012); Ghimire (2005); and YC (2010) also estimated IRR of biogas production to be up to 40% in Bangladesh. The payback period of a medium biogas plant is 4.25 years, a notable difference between small and medium-sized biogas plants.

The above discussion indicates that decision-making tools are pointing to the small-scale biogas plant regardless of the subsidy. Thus, policymakers should work on the small-scale biogas plant as a future source of energy in rural Bangladesh.

3.6. Estimation of economic evaluation on carbon trading

One of the initiatives of the Kyoto Protocols is to commence Clean Development Mechanism (CDM) with a flexible approach. The CDM approach grants the developing country to receive CER credit for its carbon reduction initiative. These CER can be exchanged, and developed countries can purchase them to comply with the Kyoto Protocols (Gofran, 2012).

Grameen Shakti is an important IDCOL partner organization for carbon emission reduction programs. It has already completed the necessary documentation for registration with the United Nations Framework Convention on Climate Change (UNFCC) for trading the CER points with the industrial's country. Bangladesh could trade the carbon emission and earn foreign currency from the developed country. The government could distribute to the incumbent biogas user to promote biogas adoption.

This study assumed that small, medium-sized, and large farms would reduce their CO2 emissions by 2.5, 3.0, and 4.0 tons, respectively, at the cost of $7/ton and earn $14.17, $19.83, and $28.83 per year, respectively (Appendix A1). As less firewood and kerosene are used, greenhouse gas emissions are reduced significantly. According to the BSP, A net CO2 reduction of 4.7 tons per plant per year in Nepal has achieved an equivalent of 660,000 tons per year for installed plants (UNCTAD, 2010).

Table 7. NPV, IRR, PBP, and BCR of different biogas plants under carbon trading.

Name	NPV (USD)	IRR (%)	PBP	BCR
Small plant	1925.55	41 %	3.59	1.95
Medium plant	1913.28	41 %	3.94	1.97
Large plant	1938.39	42%	4.29	2.01
Mean	1925.75	41 %	3.94	1.97

Another study in Ghana led by Mohammed et al. (2017) found that the biogas plant can reduce the GHG emission by 1197 tonnes/year, equivalent to $29,940 earning from the potential carbon trade market.

It is evident that Biogas provides foreign currency for the country and helps achieve a sustainable environment. In our study, Table 7 showed that Medium size plants are more viable than the other two concerning NPV, IRR, BCR. Specifically, IRR value for all plant categories is significantly higher than the 12% discount rate. In addition, regardless of the size of plants, initial capital investment can be recovered within four years, while they provide service for up to 15 years. Thus, it is evident that biogas plants can be run as a profitable business by households.

Taking all analyses into account, it was discovered that biogas plants could be installed throughout the country with sufficient cattle or poultry. As previously stated, Biogas has numerous multifaceted advantages, internal and external, social and economic, direct and indirect. As a result, the spread of biogas technology in Bangladesh's rural areas can contribute to improving health conditions and mitigating environmental degradation; it can also positively impact the socioeconomic situation in both the local and global arenas.

3.7. Bivariate relationship analysis between biogas operational status and demographic characteristics of owner

In this analysis, socio-demographic characteristics of biogas plant owners like education, occupation, and family size are considered. Table 8 shows the bi-variate between owners' operational status and socio-demographic characteristics. From Table 8, it was observed that the functional quality of biogas plants depends on the owners' educational backgrounds. The likelihood of being a biogas plant defunct decreases as the education level of the owner increases. However, no such association was observed in the case of owners' occupation and family size.

Table 8. Relation between operation status with the different demographic and key element of biogas plant.

Operational condition					
Factors		Ever defunct	Never defunct	Total	
Educational status of the respondents	Illiterate	16	1	17	**$\chi^2 = 9.07$ P = 0.053**
	1–5 years	34	15	49	
	6–10 years	66	7	73	
	11–12 years	61	12	73	
	More than 12 years	35	9	44	
	Total	241	59	300	
Occupation of the respondents	Service	5	39	44	**$\chi^2 = 2.42$ P = 0.59**
	Business	23	106	129	
	Agriculture	21	74	95	
	Others	8	24	47	
	Total	57	243	300	
Family size	1–4	19	64	83	**$\chi^2 = 2.02$ P = 0.36**
	5–8	27	131	158	
	8 +	11	48	59	
	Total	57	243	300	
Type of feed materials	Cow dung	49	220	269	**$\chi^2 = 4.98$ P = 0.28**
	Poultry litter	6	19	25	
	Mixed	2	4	6	
	Total	57	243	300	
Follow up service	no, not even when requested	38	15	53	**$\chi^2 = 39.54$ P = .000**
	no, not at al	32	14	46	
	yes. on cal	16	89	105	
	Yes, regularly	20	76	99	
	Total	106	194	300	
Quality of mason	skilled	9	9	18	**$\chi^2 = 24.7$ P =0.001**
	Unskilled	140	142	282	
	Total	149	151	300	
	No	9	25	34	
	Total	51	248	299	
Training on operations& management of BP received	No training	62	15	77	$\chi^2 = 10.66$ P = 0.045
	No training but manual was given	71	17	63	
	Some sort of training received	125	25	150	
	Total	57	258	300	

Several articles identified a lack of follow-up services and management of household biogas digesters as a critical issue for rural energy development (Chen et al., 2010). Many biogas digesters have failed due to inadequate follow-up services and management, owing to the fact that the development of household biogas digesters in rural areas focuses primarily on construction rather than management. This analysis included other key elements of BP like feed materials, follow-up service, and the skill of construction workers. Table 8 shows the Bi-variate between operational status and other key elements of biogas plants, along with chi-square values and corresponding p-values. Chi-square test ensures that there is no association between feed materials and operation.

The operational status of biogas plants (functional or non-functional) does not depend on whether the feed material is dung, poultry litter, or a mixture. Similarly, no association was observed in the case of plant size. Most importantly, a strong association was observed between the skills of construction workers, particularly the quality of the mason who was engaged in construction work. This finding indicates that the operational performance of biogas plants at large depends on the skill level of the mason.

A biogas plant constructed by a skilled mason is less likely to be undergone defunct conditions. From Table 8, another high correlation was discovered in after-sale service, leading to the conclusion that the biogas plant was most likely going to be decommissioned as a result of this.

The absence of skilled biogas plant attendants may have contributed more to the failure of most facilities in Bangladesh than any other issue. Users of biogas facilities were found to have little or no understanding of the plant's activities. While about three-fourths of the surveyed users have reported knowing the daily amount of feeding materials into their plants, the rest (about one-fourth) do not have that knowledge (Table 8), which significantly impacts the proper maintenance of the plants.

Farmers lack adequate education and training on properly operating biogas digesters and fully using the digested residue. The vast majority of biogas users are only using it for lighting and cooking. In contrast, the utilization of digester residues has a low level of use (Zhang et al., 2007). In this analysis, variables included training of users and responsible person for the operation and maintenance of biogas plants. Table 8 shows the Bi-variate between operational status and training of users and responsible person for operation and maintenance of biogas plants along with chi-square values and corresponding p-values. Table 8 shows that the functional status of biogas plants is affected by the training received by the owners for O&M of the biogas plants, with corresponding p-values. 045, which is less than 5% significant. The likelihood of a biogas plant going out of business decreases as the owner's level of training increases. However, no such association was observed in owners, regardless of whether male or female members operate biogas plants. This implies that the better the training, the more likely the biogas plants will be operational. The study came across with divergent views from the plant owners. Individuals described their overall experience regarding biogas function. Some of the lessons learned may have a beneficial impact on future development and expansion plans, while others must be investigated and addressed in order to pave the way for future biogas development across the country. The lessons could be a guiding principle for the concerned authority, where they could launch a new strategy to attract more potential customers to install biogas plants.

4. Conclusion

Biogas plant technology have emerged as a possible solution for the energy crisis. In our study, partial budgeting approach showed that biogas plant is profitable in terms of normal and discounted profit for the household. Under the financial approaches, households were found to receive optimistic results of NPV, IRR, BCR, and shorter PBP. The study came across with divergent views from the plant owners. The study revealed that education positively influenced the proper functioning of biogas plants, and the construction of biogas plants by skilled masons was an integral part of the efficient functioning of the biogas plant. It was also found that follow-up services and training had also a significant impact on the efficient functioning of the biogas plant. The findings indicated that government needs to provide subsidies for installing biogas plants in Bangladesh for encouraging potential users. So, the policymaker should ensure these factors at the field level for the mass installation of the biogas plant.

However, handling cow dung without proper knowledge can have severe consequence on the household health safety triggered by different disease containing insects, flies. Details study are needed to address the health issue and management practice for household. Besides, though biogas plants are financially benefit for the household, it lacks the commercially establishment in Bangladesh. Further study should be taken to understand the commercial feasibility of biogas plant in Bangladesh.

Declarations

Author contribution statement

Dilruba Bedana: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

M Kamruzzaman: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Md Jaber Rana: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

B A A Mustafi, Rezaul Karim Talukder: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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Appendix

Table A1. Annual benefit of biogas use (USD/year).

Items	Small	Medium	Large	Average
CO_2 emission	14.17	19.83	28.33	20.78
Health	12.86	10.12	6.43	9.80

Table A2. Labourer cost for O&M of biogas plant (USD)

Items	Small	Medium	Large
Labor hour per day	0.45	0.50	1.00
Wage rate per day	4.17	4.17	4.17
Wage rate per hour	0.52	0.52	0.52
Per day expense	0.23	0.26	0.52
Yearly expense	84.38	93.75	187.50

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