Renewable Energy 230 (2024) 120895

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Economic viability and factors affecting farmers' willingness to pay for adopting small-scale biogas plants in rural areas of Cameroon

Chama Theodore Ketuama, Hynek Roubík *

Department of Sustainable Technologies, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Kamýcka 129, Prague - Suchdol 16500, Czech Republic

ARTICLE INFO

Keywords:
Biogas
Benefit-cost ratio
Sensitivity analysis
Willingness to pay
Clean energy
Cameroon

ABSTRACT

This study provides an in-depth economic analysis to aid decision-making in the adoption of small-scale biogas technology in rural areas of Cameroon. It also provides evidence of the field investment characteristics of the biogas energy supply in rural areas of Cameroon. The methodology focused on assessing the economic viability of different sizes of biogas plants and the willingness of farmers to pay for the same. A sample of 180 farmers was selected for the study. Data collection was carried out from December 2020 to May 2021 using a questionnaire survey and participant observation. The results show that all small-scale biogas plants are economically viable. Benefit-cost ratios were 1.01, 1.19, 1.50, 1.02, 1.21 and 2.04 for the 4 m^3, 6 m^3, 8 m^3, 10 m^3, 20 m^3, and 25 m^3 biogas plants. The net present values in US dollars (USD) were 959, 1790, 2695, 2658, 6047, and 12267 for the 4 m^3, 6 m^3, 8 m^3, 10 m^3, 20 m^3, and 25 m^3 biogas plants, respectively. The internal rate of return was higher than the applied discount rate of 12 %. The minimum payback period of 2.24 years was recorded for the 25 m^3 while the maximum of 3.37 years was recorded for the 10 m^3 biogas plants, respectively. With a disproportionate increase in the cost of biogas plants by 20 % and a 20 % decrease in benefits with a discount factor, the net returns are positive, indicating that all biogas plants are economically viable. The mean willingness to pay is estimated at 13 USD or 8000 FCFA. This resulted in an average repayment period of 11.5 years. The provision of extension services, financial incentives, and regulation of the small-scale biogas market will motivate farmers to adopt the technology.

List of abbreviations

AEZ	Agroecological zone	NBP	National Biogas Programme
BGP	Biogas plant	USD	United States dollar
GHG	Greenhouse gas	B_i	Bid offered to farmer *i*
GIZ	German Development Cooperation	WTP_m	Mean willingness to pay
IEA	International Energy Agency	WTP_i	Farmer *i*'s unobservable true willingness to pay
MFI	Micro-finance Institution	y_i	Farmer's response to the bid offered
MJ	Megajoule		

1. Introduction

Enabling access to modern energy services in resource-poor countries continues to be relevant to achieving development objectives such as reducing poverty, access to drinking water, improving health and education, increasing the socio-economic role of women, and increasing agricultural production [1]. Biogas is considered an environmentally friendly alternative to unsustainable energy sources such as fuelwood and charcoal [2]. Biogas technology in Africa needs a revolution to achieve a modern energy transition [3]. The possible alignment relies partly on improving both the economic viability and farmers' willingness to pay (WTP) for the biogas plants. In recent decades, biogas technology in Sub-Saharan Africa (SSA) has witnessed the failure of hundreds or even thousands of biogas projects, limiting access to modern energy [4]. Failed biogas projects have been reported in Uganda [3], Tanzania [5], and Senegal [6]. The failure of these biogas plants has been attributed in part to poor construction and installation, substandard feeding practices, operation and maintenance issues, and inadequate training and knowledge about the technology. Since 2020, Africa is facing the first recession in 25 years, which has affected income from

* Corresponding author. author. Czech University of Life Sciences Prague, Kamýcká 129, Prague 6, Suchdol, 165 00, Czech Republic.
E-mail addresses: ketuama@ftz.czu.cz (C.T. Ketuama), roubik@ftz.czu.cz (H. Roubík).

https://doi.org/10.1016/j.renene.2024.120895
Received 9 August 2023; Received in revised form 6 May 2024; Accepted 27 June 2024
Available online 28 June 2024
0960-1481/

fossil fuel production, supply chains, and foreign direct investment patterns. This has affected access to modern energy in Africa, with the number of people without access to clean cooking fuels increasing to 970 million in 2021 [7] against 917 million in 2019 [8]. Cameroon is no exception. In 2021, 65.4 % of the total population had access to electricity [9]. In rural areas, only 24.8 % of the population had access to electricity, compared to 94.7 % in urban areas. Electricity from renewable sources, excluding hydroelectricity, serves only 1.1 % of the population. The development of renewable energy in Cameroon faces several bottlenecks with respect to policies, regulations, institutions, knowledge diffusion, technical capabilities; and financial support [10].

Since the introduction of biogas technology in Cameroon in the second half of the twentieth century (the 70s) [11], its adoption and diffusion have been very slow. The technical potential (exploited and unexploited) of small-scale biogas plants in Cameroon is estimated to range from 284,000 to 724,000 [12]. The 'technical potential' is defined as the number of households that can meet the two basic requirements – sufficient availability of both dung and water – to operate a biogas plant. In 2018, only about 500 constructed biogas plants were reported in the country [13], corresponding to a technical potential exploited of less than 1 %. This has contributed to the persistent dependence of rural households on traditional energy sources such as firewood, charcoal, and dry dung for cooking. Approximately 94 % of households in rural areas of Cameroon still use fuelwood for cooking [14]. The demand for fuelwood in Cameroon is, on average, 1kg/person/day [15]. Consequently, unwanted deforestation of the natural forest is continuing while women and children suffer other socio-economic setbacks due to fuelwood collection drudgery and use. The use of fuelwood also causes household air pollution (HAP) which is a risk factor for several diseases, such as respiratory diseases, cardiovascular disorders, adverse pregnancy outcomes and cataracts [14]. Biogas technology responds at the local level to three dimensions of sustainable development; environmentally by reducing the side effects caused by the energy supply chain and inefficient energy use: greenhouse gas (GHG) emissions, air pollution and depletion of the natural resources; economically by reducing energy dependence and by enabling the activities that generate business and wealth, e.g. by increasing local business investment in renewable energy and energy efficiency; and socially by improving human health, creating jobs and involving the citizens in decision-making processes [16]. In rural areas of Cameroon, most farmers practice subsistence farming that combines agriculture and animal husbandry. With the increasing cost of inorganic fertilisers in the local markets [17], digestate, a by-product of the biogas production process (anaerobic digestion) is a potential alternative that can contribute to reducing the farmers' cost of production. Biogas is also a source of skills enhancement and employment for rural areas [18]. In refugee settlements in Africa and other parts of the world, biogas technology is used to provide clean cooking energy while improving sanitation [19].

Biogas technology relies on the process of anaerobic digestion to produce biogas. Anaerobic digestion has been identified as a renewable energy pathway for providing clean fuel to energy-deficient households around the world [7]. Anaerobic digestion is a chemical process that breaks down organic matter from plant and animal origin in the absence of oxygen to valuable biogas. Biogas is a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S) and other trace elements. Biogas constitutes approximately 50–70 % methane and 30–50 % carbon dioxide. Biogas produced in Cameroon has an acceptable quality for use in appliances such as biogas cookers and lamps [20]. The mean calorific value of biogas is approximately 22 MJ/m^3. A biogas volume of 0.2 m^3 is equivalent to 1 kg of fuelwood, 0.09 kg of liquefied petroleum gas (LPG), 0.13 L of kerosene, 0.15ℓ of gasoline (petrol) and 0.13ℓ of diesel. The average biogas consumption range of 0.1–0.3 m^3/person per day (assuming one warm meal per day). The specific gravity of biogas with a composition of 60 % methane and 40 % CO_2 is 0.93 [21]. The production of biogas releases a by-product known as digestate (or bio-slurry). It consists of approximately 93 % water and 7 % dry matter, of which 4.5 % is organic and 2.5 % inorganic matter [22]. The hydraulic retention time (HRT) ranges from 20 to 50 days in Cameroon as well as in India [23] and China [24].

In rural areas of Cameroon, as in other developing countries, the most widely used designs of biogas plants are the fixed-dome (Fig. 1a) and the floating drum (Fig. 1b). The choice of the design depends on the performance of the biogas plant. These BGPs are constructed with different materials, including plastic, masonry (concrete/brick), steel and resin-reinforced fibreglass. Farmers use a variety of organic waste, including food waste, crop residues, animal dung and faecal sludge (septage), as feedstock for their BGPs. The predominantly used design of the BGPs in Cameroon is the masonry fixed-dome (often built under the ground to maximise space, increase structural stability and insulation). In Cameroon, a biogas plant of 8 m^3 can meet the energy needs for cooking and lighting of most households [25].

To mobilise the available biogas potential in rural areas of Cameroon, efficient use of the available resources owned by farmers is required. As a result, the economic viability and willingness to pay become important considerations for implementing financially sustainable biogas projects with long-term ownership. The economic viability seeks to optimise the monetary surplus from utilising biogas and organic fertiliser against the capital investment cost. The economic viability analysis essentially determines whether the investment in biogas technology is profitable or not and the related financial risks. The economic viability assessments of small-scale biogas technology have been performed across the world to support decision-making to adopt and obtain optimal benefits from it. Some of the studies include in Uganda [26], Bangladesh [27], Ethiopia [28], and Pakistan [29]. Most of these studies showed that small-scale biogas technology is economically viable. However, it was revealed that the revenue from energy substitution was insufficient to cover the project cost without the revenue from bio-slurry and environmental benefits. As such, for every biogas project, the viability assessment is crucial to achieve best outcomes. Although biogas technology is economically viable at the household level, farmers have to be willing to pay for it, to enjoy the benefits. Farmers' WTP for biogas plants refers to the amount of money that they are willing to spend or invest in the technology. Knowledge of WTP enables the understanding how farmers perceive the value and social acceptance of biogas technology. One of the major barriers to domestic biogas technology in Sub-Saharan Africa is the lack the financial capacity to pay for the capital investment cost [4]. Consequently, the amount that most farmers are willing to pay has in most cases been far less than the market price of the biogas plants. This was evident in Nepal [30], Uganda [31], Madagascar [32] where assessments were conducted. These studies suggested that the provision of environmental income (via carbon credits), credit facilities, low-cost biogas plants, adult education, and further promotion could lead to more rapid and widespread adoption.

Despite the application of the concepts of economic viability and WTP to inform farmer's decision to adopt small-scale biogas technology in different parts of the world, no formal studies have been conducted for the case of Cameroon. To this effect, the following research questions were formulated: Are small-scale biogas plants in rural Cameroon economically viable? Are farmers willing to pay for the biogas plants? This study aims to aid decision-making in investing and obtaining optimal benefits from small-scale biogas technology in rural areas of Cameroon. The economic viability was assessed though the cost-benefit analysis. Farmers' WTP and the influencing factors were assessed using contingent valuation and probit model. Data were collected from December 2020 to May 2021 in Cameroon using questionnaire survey and participant observation from 180 rural farmers, amongst which 45 owned operational biogas plants of sizes ranging from 4 m^3 to 25 m^3. This study is limited to rural biogas plants and does not include the situation in peri-urban areas of the country. This study provides additional information to farmers, policymakers, and other investors on the economic viability and the factors that influence the willingness of farmers to pay for small-scale biogas technology in rural areas of

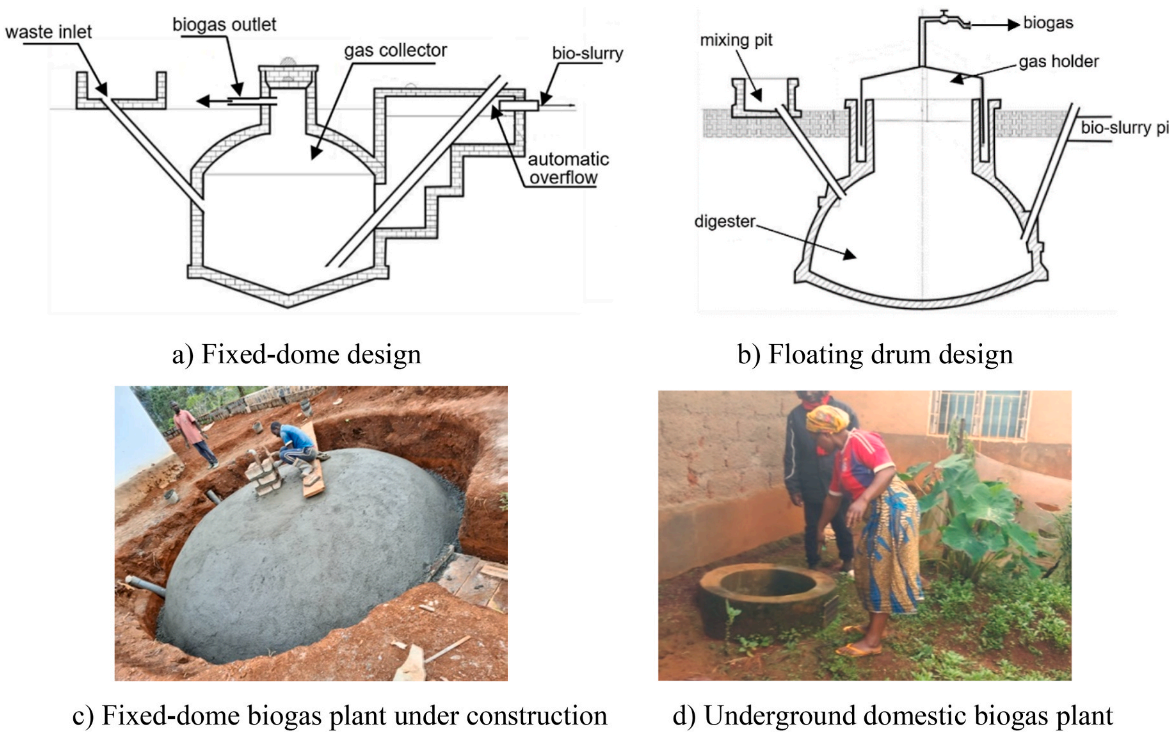


Fig. 1. Main designs of biogas plants in Cameroon.
Source: Authors

Cameroon.

2. Methodology

2.1. Study area

This study was carried out across the five agroecological zones (AEZs) of Cameroon, as shown in Fig. 2. Cameroon is located between Cameroon map latitude 1° and 13° North and longitude 8° and 17° East of the Greenwich meridian. The climatic conditions and vegetation make possible the production of crops and livestock-rearing activities as well as biogas production. Agriculture and animal husbandry are the main sources of livelihood for more than 60 % of the rural population of Cameroon [33]. The primary biogas feedstocks in rural areas of Cameroon are cow dung and other livestock manure (horses, pigs, donkeys, poultry, goats, rabbits). A very small amount of food waste is used for biogas production in rural households.

2.2. Sampling technique and data collection

The study targeted farmers including users and non-users of biogas technology. Equation (1) [34] was used to determine the size of a representative sample of the farmers due to their dispersed settlements and owning very few biogas plants. Given that the technical potential of biogas plants in Cameroon ranges from 284,000 to 724,000, an average of 504,000 biogas plants was used to estimate the sample size for the survey.

$$n = \frac{p(100 - p)z^2}{E^2} \tag{1}$$

where n is the required sample size, p is the percentage of the average technical potential (86.4 %), z is the value corresponding to the confidence level of 95 % (1.96), and E is the margin of error (±5 %). Using this method, a sample of 180 farmers was required for this study. Multi-stage sampling approach was used to identify the farmers (respondents).

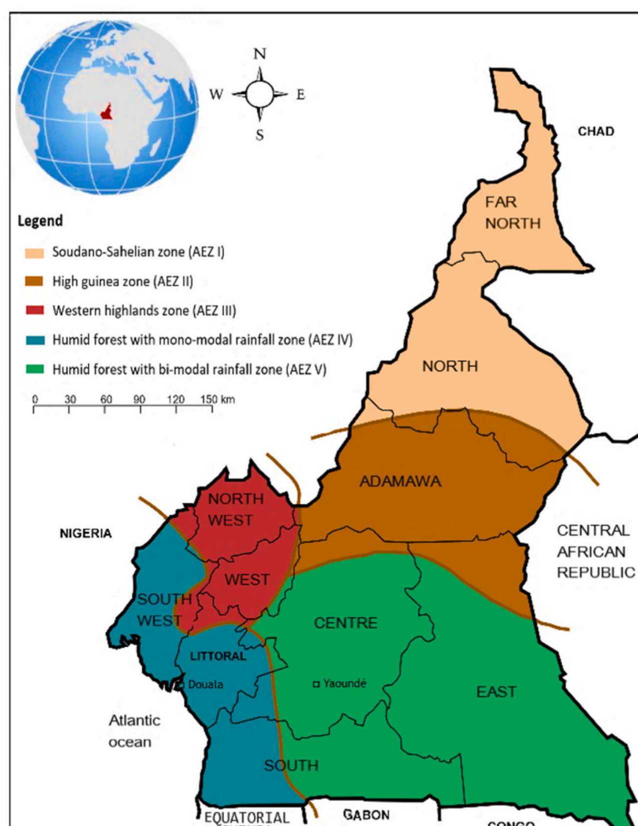


Fig. 2. Map of Cameroon showing the different agroecological zones.
Source: authors

The first stage involved quota sampling where 36 farmers were sought from each AEZ comprised of users (with functional biogas plants) and non-users of biogas technology. In the second stage, snowballing approach was used to search for biogas users. Once a biogas user was identified, this farmer provided information to aid in the identification of the other user or users. Given that these biogas users were scarce, the quota was completed by randomly selecting farmers (non-biogas users). This approach enabled the identification of all the 180 farmers required for this study. Table 1 shows the distribution of the farmers for the different AEZs. Questionnaire surveys were administered to collect socio-economic and willingness to pay data from all the respondents. For biogas users, the questionnaire was used to collect additional data on the different costs (installation, labour and maintenance of the biogas plants) and revenues associated with the use of the biogas plants. Collecting data across the five AEZs aided in obtaining a sample whose results can be validated across the country. The biogas feedstocks in AEZ I and II is dominantly cow dung, AEZ III has a higher variety of feedstocks including in addition to cow dung, poultry and plant residues, while AEZ IV and V uses mostly pig waste as biogas feedstock. All these feedstocks produce sufficient and similar quality for biogas for household cooking and lighting [20].

2.3. Data analysis

Data analysis was performed to determine: i) the economic viability of biogas plants using cost-benefit analysis and sensitivity analysis; ii) the willingness of farmers to pay using contingent valuation; and iii) the factors influencing farmers' willingness to pay for the BGPs using the probit regression model. The marginal effects were determined as an indication of how much the WTP (dependent variable) varies when each independent variable changes. Before the collected data were used for the analysis, they were cleaned, categorised and coded. The software used to perform the different calculations and statistical analysis were Microsoft Office Excel and the Stata software version 16.0.

2.4. Economic viability analysis

The cost-benefit analysis (CBA) was performed to determine the economic viability of small-scale biogas plants in rural areas of Cameroon. The CBA is an appropriate tool to assess the viability of biogas technology [23,26,35]. The benefit-cost ratio (BCR) as the key indicator for the viability assessment was estimated. Other related indicators estimated were the net present value (NPV), internal rate of return (IRR), and payback period (PBP).

2.4.1. Assessment of costs and benefits of biogas plants

The main costs associated with the biogas plant are the capital and installation costs, as well as operation and maintenance costs. These costs comprise all expenses for acquiring materials/equipment and installing the BGP and accessories. The costs of the biogas plants were estimated based on the observation of invoices used during the construction of the biogas plants. When the invoices were not available, farmers were asked (recall method) about the cost of materials and labour they incurred during the construction of the biogas plants. Cost variation in the capital investment cost of the same size of biogas plant in different parts of the country due to variations in the cost of the construction materials, the design and size of the biogas plant, and the local labour or installation costs (depending on the bargaining power of the project owner). The materials used for the construction of the biogas plants susceptible to depreciation were masonry materials (bricks and concrete). The annual depreciation was assumed at 4 % of the capital and installation costs [26]. The cost of land was excluded from the analysis because the households already owned land which was previously acquired with or without the intention of acquiring a biogas plant. However, adding the cost of land will evidently increase the capital investment cost and reduce the viability of the BGPs. The annual operation and maintenance (O&M) costs considered in this study were the costs of collecting feedstocks, maintenance and depreciation of the biogas plant. It is assumed that running a domestic biogas plant takes about an hour a day or a man-day of approximately 0.13, considering that a man-day is 8 h of work. The average annual maintenance cost is approximately 4 % of the capital cost [36].

The benefits considered in the viability assessment are the annual monetary values (revenues) from the use of the biogas plants or technology as an alternative source of fuel and organic fertiliser. Fuel substitution benefits were assessed as the savings from the acquisition of the other previously consumed fuels, mainly fuelwood and kerosene. This included the expenditures incurred in the sourcing of fuelwood and kerosene (buying in some cases and transporting to the household). Fuelwood was used for cooking while kerosene was used for lighting. During the study period, fuelwood was collected from the forests or bought in bundles of 10–40 kg across the country. A fuelwood bundle of 32 kg was used for approximately 6 days. The benefits from organic fertilisers were estimated by calculating the monetary equivalent of inorganic fertiliser that have been replaced with digestate from the biogas plant. For digestate, the values were estimated as the amount of money saved from substituting inorganic fertiliser with digestate. This amount varied from one farmer to the other. There is no standard market price of digestate in Cameroon. The average monetary values of the biogas plants were calculated by multiplying the daily estimated values (of biogas, digestate, and labour-saving) by 365 days to obtain the annual benefits.

Table 1
Distribution of farmers.

Location	Administrative regions	Non-biogas users	Biogas users
AEZ I	North and the Far North	33	3
AEZ II	Adamawa Region and the northern part of the Mbam Divisions (Centre Region) and Lom et Djerem (East Region)	20	16
AEZ III	West, Northwest Regions and parts of South West Region	27	9
AEZ IV	Littoral and South West Regions	31	5
AEZ V	Centre, East and South Regions	24	12
Sub-total		135	45
Total		180	

2.4.2. Estimation of economic viability indicators

Key indicators to determine the economic viability of biogas plants include the benefit-cost ratio (BCR), net present value (NPV), internal rate of return (IRR), and payback period (PBP). For each size of BGP, the benefit-cost ratio was estimated using equation (2).

$$\text{Benefit} - \text{Cost Ratio} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \tag{2}$$

where B_t is the benefits in year t; C_t is the costs in year t; i is the interest rate of the project, n is the number of years that the BGP is expected to operate (i.e. lifespan of the biogas plant, considered at 15 years). If the ratio is greater than one (i.e. $B/C > 1$), the biogas project is viable otherwise, ($B/C < 1$), reject the biogas project as it is not viable [37].

Before estimating the BCR, the net present value (NPV) is first estimated as the sum of the future cash flows over 15 years (lifespan of the BGPs). A 15-year lifespan was selected for the biogas plants in Cameroon based on the farmer's experience on the lifespan of BGP and literature such as [10]. A discount rate of 12 % was selected according to Refs. [26, 38], applicable to the evaluation of rural projects and an average in Cameroon. For the biogas project to be economically viable, the NPV is expected to be positive. Otherwise, it will not be a viable energy source to the farmer.

With a known NPV, the IRR was estimated for the different BGPs. The IRR is the discount rate at which the NPV equals to zero as shown in equation (3). If the IRR is greater than the interest rate, the biogas project is viable. On the contrary, if the IRR is less than the interest rate, the biogas project is not viable. In comparing project options, the higher the IRR, the more viable is the project.

$$0 = \text{NPV} = -\text{C}_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \tag{3}$$

The PBP which is the number of years required to recover the investment cost of the biogas plant is estimated with equation (4).

$$\text{Payback period} = \frac{\textit{Cost of installation}}{\textit{Annual profit}} \tag{4}$$

2.4.3. Sensitivity analysis

A sensitivity analysis was performed by changing each of the input factors (cost and benefits) at a time and determining the output (NPV and IRR). In the calculations, a 20 % increase or fall in both the cost and benefit of each biogas plant is considered. Several factors affect the costs and benefits of BGP in Cameroon including the cost of construction materials, geographical location, availability of feedstock, inflation, and marketing of digestate. In Cameroon, the BGPs are constructed with different materials, including masonry, plastic and reinforced fibreglass. Having considered the masonry biogas plants in the cost estimations, the construction of the same BGP size with plastic and fibreglass materials can lead to a 20 % reduction in the cost respectively. Depending on the location of the BGP in the country, the construction cost could increase. Distant collection of feedstocks has contributed to increased cost of biogas production. Price volatility due to inflation could also increase or decrease the capital investment and production costs. The benefits from the BGPs are also affected in some cases by the availability of inputs (water and dung) and marketing of digestate.

3. Contingent valuation and probit regression of willingness to pay factors

The contingent valuation method was applied through direct questionnaire surveys of farmers to state their willingness to pay for the domestic biogas plants. WTP is the maximum amount of money an individual would give up in exchange for all the benefits associated with an environmental resource or technology. A farmer's WTP is the farmer's surplus attached to the equivalent price change for substituting fuelwood (and related energy sources) and inorganic fertilisers with biogas technology. Despite the WTP methodological criticisms raised by Ref. [39] as a bad idea to measure the value of nonmarket items (or goods), the method is still relevant. Contingent valuation elicitation was done in three steps; i) presenting the technology to each farmer and asking if the farmer would be willing to pay for it; and ii) asking how much the farmer is willing to pay for the technology by presenting the different random bids. In practice, the elicitation was done as follows:

> 'To *produce biogas with the 8 m^3 biogas plant, enough for a household of 5 to 7 members, an estimated 60 to 80 kg of organic waste* per *day is required. This requires approximately 5 mature cows or 600 poultry fowls or 50 pigs and 60 to 80 L of water'*.

While presenting the operation of the BGP to the farmer using photos, it was explained that the organic waste is mixed with water before feeding into the biogas plant.

> *'If a BGP that can adequately substitute fuelwood and other cooking fuels and provide you with organic fertiliser is installed at your home, would you be willing to use it? Would you be willing to pay for it? If yes, how much would you be willing to pay (random bids' corresponding values in FCFA presented) every month for it, considering that the estimated cost of the biogas plant and appliances is 1121400 FCFA (1800 USD)?'*

To acquire a biogas plant in Cameroon, farmers usually save for months or even years in economic interest groups or financial institutions (microfinance and banks). A number of farmers, *i* responded 'yes' to the CV question if their true WTP was equal or higher than the random bids presented to them, otherwise their responses were 'no'. The responses were represented as a dummy variable y_i that took the value of 1 if a farmer responded 'yes' and 0 otherwise, as shown in equation (5).

$$\text{y}_\text{i} = \begin{cases} 1 \text{ if } WTP_i \geq B_i \\ 0 \text{ if } WTP_i < B_i \end{cases} \tag{5}$$

where WTP_i is farmer *i*'s unobservable true *WTP* and B_i is the random bid presented to each farmer (as shown in Table 6). The bids were determined in relation with the monthly average cost of cooking energy per household, which was between USD 1.6 and 28.8.

To assess the factors influencing farmers' WTP, a representative model using the linear function as shown in equation (6) is used.

$$WTP_i = \mu X_i + \varepsilon_i, i = 1, 2, 3, \ldots\ldots, \text{n} \tag{6}$$

where μ is a vector of parameters, X_i is a vector of independent variables, and ε_i is an error term. The probability to get the 'yes' responses given the independent variables which affected WTP_i (Pr ($y_i = 1| X_i$) is the probability that the unobservable WTP of each farmer (WTP_i) is more or equal to the bid offered to the farmer (B_i) and can be expressed as in equation (7):

$$P_i = (y_i = 1|X_i) = Pr(WTP_i \geq B_i)Prob(\mu\, X_i + \varepsilon_i \geq B_i) \tag{7}$$

where B_i was the bid presented to farmer *i. X_i* represents the independent variables that were considered to affect y_i.

The probit model was appropriately used to estimate the probability of getting 'yes' responses from farmers, and it depended on the random bids offered and other independent variables, as shown in equation (8).

$$y\_(i) = \beta\_(0) + \beta\_(1)\,B\_(i) + \beta\_(2)\,X\_(1i) + \beta\_(3)\,X\_(2i) + \ldots + \beta\_(k)\,X\_(k-1)i\big) + \varepsilon\_(i) \tag{8}$$

where $X_{1}, \ldots, X_{k\text{-}1)i}$ are the selected independent variables that affect y_i. These variables are presented in Table 2. The coefficients β_0 and β_i are measures of the changes in ratio of the probabilities, also known as the

Table 2
Variables used in the probit model for assessing the factors influencing farmer's willingness to pay for biogas plant.

Variable	Description	Measurement	Expected sign
X_1	Bid offered by farmer (USD)	Continuous	–
X_2	Educational level (number of years)	Continuous	±
X_3	Number of persons in farmer's household (number)	Continuous	+
X_4	Total farmland owned (ha)	Continuous	+
X_5	Expenditure on other energy sources that can be substituted with biogas (USD)	Continuous	+
X_6	Farmer's annual income (USD)	Continuous	+
X_7	Sufficient feedstock to operate a biogas plant (1 = yes; 0 = otherwise)	Binary	+
X_8	Water availability (1 = yes; 0 = otherwise)	Binary	+
X_9	Access to subsidies, loans and credits (1 = yes; 0 = otherwise)	Binary	+

Note: A positive sign indicates that an increase in the independent variable leads to an increase in the probability to get the 'yes' response. However, a negative sign indicates that an increase in the independent variable leads to a decrease in the probability to get the 'yes' response. Note: 1 USD = 623 FCFA.

odds ratio. Three levels of significance of 90 %, 95 % and 99 % (or $\alpha = 0.1$, $\alpha = 0.05$, and $\alpha = 0.01$) of the model were analysed using the Stata software. According to Ref. [40], the factors that predominantly affect household willingness to pay for domestic biogas plants as a substitute for biomass energy for cooking and lighting include socioeconomic factors such as household income, household energy cost, land ownership, and livestock practices [40]. Apart from the latter factors, the availability of raw materials, financial/non-financial incentives, and awareness campaigns about the benefits of biogas technology, technical factors, political commitment, and institutional framework usually play a significant role in the sustainable adoption and development of biogas energy technology in rural areas [41]. The mean willingness to pay (WTP_m) was calculated using equation (9).

$$WTP_m = -\left(\widehat{\beta}_0 + \widehat{\beta}_2\overline{X}_{1i} + \widehat{\beta}_3\overline{X}_{2i} + \ldots + \widehat{\beta}_k\overline{X}_{(k-1)i}\right) / \widehat{\beta}_1 \quad (9)$$

4. Results and discussion

4.1. Descriptive statistics

A total of 45 functional biogas plants were identified and distributed according to the sizes of the biogas plants of 4 m^3 (9 %), 6 m^3 (11 %), 8 m^3 (51 %), 10 m^3 (16 %), 20 m^3 (11 %) and 25 m^3 (2 %) respectively. The biogas plants were the fixed-dome ($n = 42$) and the floating drum ($n = 3$) designs respectively. The total volumetric capacities of these biogas plants ranged from 4 m^3 to 25 m^3. The average age of the farmers was 36 years, with minimum and maximum ages being 19 and 79 years, respectively. The gender distribution of the respondents was 118 (66 %) males and 62 (34 %) females. The educational distribution of the respondents showed that 102 (57 %) had no formal education, 56 (31 %) had primary education, 19 (11 %) had secondary education and 3 (2 %) had tertiary education. The average household size was 6 members (±1). Land ownership by farmers was assessed as the total of residential and farmland and having a sufficient area for the construction of the BGP. The number of farmers who owned enough land to construct a BGP was 164 (91 %), while farmers who did not own sufficient land to build a BGP was 16 (19 %). The average land size owned by each farmer was 3 ha, while the maximum size was 28 ha. The monthly expenditure by a farmer to provide energy for cooking and lighting for the household ranged from a minimum of 1.6 USD to a maximum of 28.8 USD; meanwhile, the average expenditure was 3 USD. The annual incomes of the farmers from agriculture and livestock activities ranged from 144 to 24000 USD, with an average of 1809 USD. When asked if farmers would be able to have enough feedstock from livestock and agricultural activities for the operation of the 8 m^3 biogas plant, 109 (61 %) declared that they were able to provide, while 71 (39 %) could not. Given that the feedstock is mixed in a 1:1 ratio with water before feeding into the BGP, 144 (80 %) of the farmers declared that they were able to access water, while 36 (20 %) declared that they did not have access to water to feed the biogas plant. With regards to subsidies, loans and credits, most of the farmers (94 %) did not have access. Only as little as 6 % had access. The farmers who had access, benefited from the National Biogas Programme (NBP) that was implemented from 2010 to 2014, other government projects and non-governmental organisations (NGOs). During the NBP, selected farmers were provided with subsidies up to 30 % of the total cost of BGP to reduce the initial investment cost [25]. In most developing countries, subsidy has motivated farmers to adopt biogas technology [42,43]. The micro-finance institutions (MFI) and banks do not yet have frameworks to provide loans to farmers to fund biogas projects. As promised during the NBP, the credit framework has not been developed, and so it is not operational in financial institutions. The bid amounts varied from a minimum of 8 USD to a maximum of 160 USD. The descriptive statistics are summarised in Table 3.

Table 3
Descriptive statistics of variables used in probit regression.

Variable	Mean value	Stand. Dev.	Minimum	Maximum
Bid offered by farmer (USD)	10.44	18.02	8	160
Educational level (number of years)	8.61	4.67	0	22
Number of persons in farmer's household (number)	5.82	2.87	1	17
Total farmland owned (ha)	3.07	3.43	0	28.80
Expenditure on other energy sources that can be substituted with biogas (USD)	3.03	2.93	1.6	28.8
Farmer's annual income (USD)	2007.84	2604.92	144	28800
Sufficient feedstock to operate a biogas plant (1 = yes; 0 = otherwise)	0.91	0.28	0	1
Water availability (1 = yes; 0 = otherwise)	0.90	0.29	0	1
Access to subsidies, loans and credits (1 = yes; 0 = otherwise)	0.05	0.23	0	1

4.2. Cost of small-scale biogas plants in Cameroon

The construction costs vary with the size of the biogas plant. The average installation or fixed cost of the biogas plant was estimated at 900 USD for the 4 m^3 BGP and up to 6000 USD for the 25 m^3 BGP. In addition to the size of the biogas plant, the distance from the source of construction materials contributed to the variation in the cost of the biogas plants. Biogas plants in the northern part of the country (AEZ I and II) were more expensive than in the southern part due to the difficulty to access the construction materials. The average cost of 8 m^3 biogas plant in Cameroon (1800 USD) was higher than in other countries such as 1130 USD in Uganda [26], 641 USD in Bangladesh [27], and 689 USD in Ethiopia [28]. According to the farmers, the high labour costs contributed to the high installation cost. Approximately 70 % of the biogas plants were fully funded by the farmers. The costs of the other 30 % of the BGPs were offset by subsidies from the government and civil society. The annual operation and maintenance cost was estimated as 4 % of the initial investment cost. So, the O&M cost increased from 36 USD for the 4 m^3 BGP to 240 USD for the 25 m^3 BGP.

4.3. Benefits of small-scale biogas plants in Cameroon

The survey showed that farmers obtained several socio-economic benefits from the use of their biogas plants. The use of biogas led to smoke reduction in all the farmers' households. These farmers revealed that they have less eye problems due to the reduction in smoke. An estimated 91 % of the farmers reported that sanitation improved in their homes and the surroundings. Biogas technology enabled 67 % of the farmers to save more money to pay for the education of their household members. Biogas consumption led to a time savings of an average of 9 h per week initially spent on fetching fuelwood and other energy sources for their households. These farmers revealed that the extra time was spent to engage in more farming activities, carrying out house chores and other social activities such as attending community meetings and leisure. The economic benefits included an increase in the income of the biogas user households. The monetary benefits of the use of biogas plants include the savings in fuel consumption and the equivalent cost of inorganic fertilisers replaced with digestate. The average annual monetary benefits from fuel substitution amounted from 120 USD for the 4 m^3 and up to 1080 USD for the 25 m^3 biogas plants. The reduction in the consumption of fuelwood by farmers' households is directly related to the reduction in the anthropogenic pressure on forests. This provides environmental benefits from the use of biogas technology.

Farmers applied both liquid and dried digestate to their farms. Biogas users were also able to significantly replace (an average of 70 %) the amount of inorganic fertiliser used on their farms with digestate. A total of 41 (91 %) out of the 45 farmers revealed that the amount of digestate they produced did not meet the fertiliser needs of their farm. These were mainly the owners of the 4 m^3–10 m^3 biogas plants. For the 20 m^3, 25 m^3 and some of the 10 m^3 biogas plants, digestate was highly wasted due to the perception that digestate has a lower quality than the inorganic fertiliser. So, the digestate was usually given to other farmers for free, and very little was sold at an average price of 4.1 USD per 50 kg bag of dry digestate. When the farmers were asked about the marketing of the digestate, they revealed that it is not well known and accepted by farmers. Only one farmer sold liquid digestate at a price of 2.4 USD per 5 L. The sale of digestate will increase the revenue from the biogas plants, thereby optimising the benefits from it. According to Refs. [44,45], digestate increased crop revenues by an average of 25 %. However, it is recommended to apply the digestate at a rate of 10–20 tons/ha in irrigated areas and 5 tons/ha in dry farming to have a significant increase in yields.

4.4. Economic viability of small-scale biogas plants in Cameroon

The net present values in USD were 959, 1790, 2695, 2658, 6047, and 12267 for the 4 m^3, 6 m^3, 8 m^3, 10 m^3, 20 m^3, and 25 m^3 biogas plants, respectively. That is, for every dollar invested, the returns increased from the 4 m^3–25 m^3 biogas plants. This indicates that the larger the size of a biogas plant, the higher its profitability. A representative relationship between the exponential transformation of the NPV and the sizes of the BGPs is shown in Fig. 3. The estimated benefit-cost ratios for the different sizes of BGPs were greater than 1, indicating that biogas technology is a viable energy source for farmers. The payback period ranged from a minimum of 2.24 years for the 25 m^3 BGPs to a maximum of 3.37 years for the 10 m^3 BGPs. The 8 m^3 BGPs had the lowest PBP for the BGPs, lower than or equal to 10 m^3. The internal return rate for all biogas plants was greater than the discount rate of 12 %, indicating that the BGPs were economically viable. The most profitable biogas plant based on the IRR was the 25 m^3 BGP (45 %), and the least was the 4 m^3 BGP (25 %). The 8 m^3 BGP still retained the highest IRR (36 %) for the BGPs equal to or lower than 10 m^3. While it is worth noting that the small-scale BGPs are economically viable in Cameroon, the viability is largely dependent on the availability of feedstock, water and the management of the biogas plant. The viability of biogas technology is affected by the daily gas production capacity, feedstock, retention time, location, cost of substitutes, storage capacity, subsidy, and construction materials [37]. Therefore, to sustain viable biogas projects, good production and advertising management practises are required.

4.5. Sensitivity output

The sensitivity results at 12 % discount rate show that the increase in costs leads to a proportionate decrease in the NPV for all the biogas plants and vice versa. The IRR also decreases, rendering the investment less profitable. In contrast, an increase in benefits tends to increase NPV and IRR, and vice versa. In both cases, the NPV remains positive while the IRR is far above 12 %, indicating that the BGPs will be more profitable with the reduction in the cost. In all cases, the 25 m^3 biogas plant had the highest IRR, representing the most profitable biogas plant. The increase in cost without optimising the benefits from the biogas plants will reduce the IRR, leading to the non-profitability of the biogas plants (see Table 5).

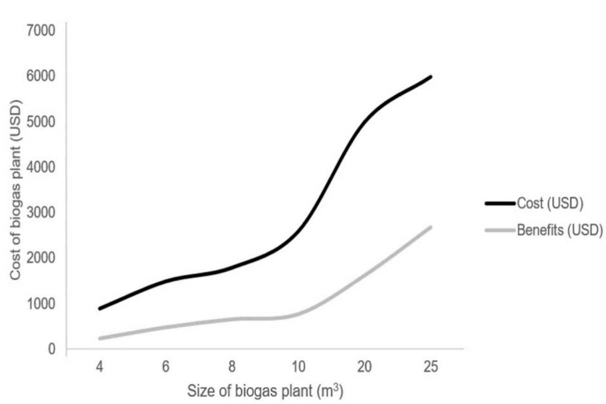
4.6. Farmers' willingness to pay for biogas plants in Cameroon

The hypothetical farmers' WTP for the 8 m^3 biogas plants as a function of the bid amounts is shown in Table 6. Of the 180 respondents, 63 (35 %) respondents responded 'no' to the CV question and were therefore unwilling to pay for the BGP. The other 117 (65 %) respondents had either already paid or were willing to pay for the BGPs and so responded 'yes' to the CV question. An estimated 36 % of the farmers were willing to pay 8 USD per month (or annual contribution of 96 USD). This means that for the 8 m^3 BGP costing approximately 1800 USD (Table 4), 36 % of farmers will take approximately 18.75 years to pay for it. Should an average repayment period of 3 years be considered, only 8 % of the farmers are willing to pay the full cost of the BGPs.

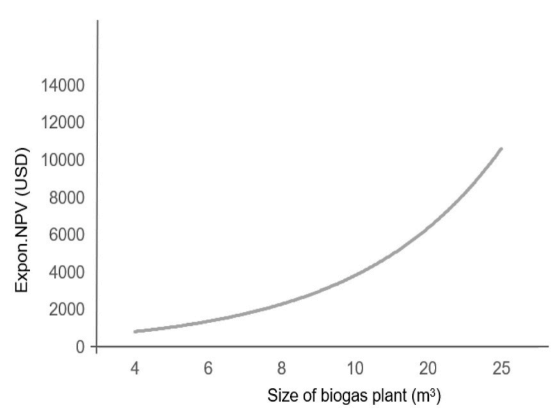
The factors affecting the willingness of farmers to pay for the biogas

Table 4
Economics of small-scale biogas plants in rural areas of Cameroon in 2021.

Indicator	Size of BGP (m^3)					
	4	6	8	10	20	25
1. Costs of the biogas plants (USD)						
Total construction cost	900	1500	1800	2600	5000	6000
Annual operation and maintenance cost (A)	36	60	72	104	200	240
2. Annual revenue from the biogas plants (USD)						
Fuel substitution	202	362	472	608	986	1752
Inorganic fertiliser substitution	107	181	260	268	836	1170
Total annual revenue (B)	309	543	732	876	1822	2922
Net annual revenue (B-A)	273	483	660	772	1622	2682
3. Other						
Net present value (USD)	959	1790	2695	2658	6047	12267
Benefit-cost ratio	1.01	1.19	1.50	1.02	1.21	2.04
Internal rate of return (%)	25	32	36	29	32	45
Payback period (years)	3.30	3.11	2.73	3.37	3.08	2.24



a) Cost and benefits of BGPs



b) NPV vs size of the biogas plants

Fig. 3. Economic viability of biogas plants.

Table 5
Changes in NPV and IRR due to 20 % increase and decrease in costs and benefits of BGPs at a discount rate of 12 %.

Size of BGP (m^3)	4	6	8	10	20	25
a) 20 % increase in cost						
NPV (USD)	779	1490	2335	2138	5047	11067
IRR (%)	21	26	30	24	26	37
b) 20 % decrease in cost						
NPV (USD)	1139	2090	3055	3178	7047	13467
IRR (%)	32	40	36	37	32	45
c) 20 % increase in benefits						
NPV (USD)	1333	2448	3594	3710	8257	15920
IRR (%)	31	38	44	35	39	54
d) 20 % decrease in benefits						
NPV (USD)	591	1132	1796	1606	3838	8613
IRR (%)	20	25	29	23	25	35

plants are summarised in Table 7. The estimated variance inflation factor (VIF) showed that the values ranged from 1.03 to 2.33, with a mean of 1.36. This indicates that there is no multicollinearity in the independent variables of the model. Hence, all variables were accepted to determine the willingness to pay for the biogas plants.

Factors that had a very significant effect ($\alpha \leq 0.01$) on the WTP of the farmer for biogas plants in Cameroon were the bid amount, expenditure on other energy sources and the availability of subsidies, loans, and credits. The farmer's income and the availability of feedstock had significantly high effects ($\alpha \leq 0.05$) on the WTP of the farmer. Water availability had a significant effect ($\alpha \leq 0.1$) on farmer's WTP. Factors that did not show any significant effect on the farmer's WTP were the level of education, the size of farmer's household and the land owned by the farmer. The bid amount was a hypothetical variable that was used to assess how farmer's purchasing power influences WTP for the BGPs. It was negative and had a highly significant effect. This means that the higher the bid amount is proposed, the probability that a farmer will not be willing to pay for the BGP is 0.08. This explains why the higher the farmer's income, the probability of WTP increases by 0.05. Compared to the farmer's income, the energy expenditure needed by the farmer exerts a greater influence on the farmer and has the probability of increasing the WTP of 0.30. To the farmers, investing in biogas technology could help reduce or eliminate the expenditure on other energy sources. Farmers who received subsidies to construct their BGPs testified that the construction burden was reduced, thereby increasing the willingness to pay their share of the construction or investment cost. During the National Biogas Programme which lasted from 2010 to 2014, the farmers were provided with a subsidy of 30 % of the initial investment cost to construct their BGPs [25]. To other farmers, if they can have access to loans and credit, they would be willing to adopt the BGPs. This was justified by the positive and highly significant effect that subsidies, loans, and credit had on the farmer's WTP. As such, the increase in subsidies has a probability to increase WTP by 0.08. Subsidies also tend to reduce the payback period of the biogas technology (per the farmers investment cost recovery). Regarding feedstock, farmers who could access it enough to run the 8 m^3 biogas plant were more willing to pay. This can be justified by the positive and highly significant effect of feedstock availability on WTP. Feedstock availability has the probability to increase WTP by 0.24. Water availability, which is a prerequisite to run the BGP, showed a positive and significant effect on WTP. The more water is available for biogas production, the probability of a farmer's WTP increases by 0.01. For the rural BGPs, the feedstock-water ratio is usually 1:1.

Table 7
Factors affecting farmer's willingness to pay for biogas plants in rural areas of Cameroon.

Variable	Coefficient	Stand. Error	VIF	Marginal effect
Bid offered by farmer	−0.0094***	0.001	1.23	−0.086
Educational level	0.3786	0.364	1.12	0.016
Number of persons in farmer's household	0.3275	0.005	1.08	0.013
Total farmland owned	−0.8535	0.005	1.36	−0.041
Expenditure on other energy sources that can be substituted with biogas	0.0027***	0.009	1.95	0.310
Farmer's annual income	0.0730**	0.000	2.33	0.160
Sufficient feedstock to operate a biogas plant	0.1422**	0.037	1.08	0.240
Water availability	0.0698*	0.041	1.03	0.014
Access to subsidies, loans and credits	0.0140***	0.072	1.04	0.088
Constant	0.4212	0.093	–	–

N = 180; Log likelihood = −10.1517134; LR χ^2 (9) = 14.39; Pseudo R^2 = 0.6334. * 10 % significance level; ** 5 % significance level; *** 1 % significance level.

Factors that did not show a significant effect but had a positive effect on farmer's WTP (and their probability levels) are educational level ($p = 0.016$) and household size ($p = 0.013$). Land ownership showed a negative and non-significant effect on farmer's WTP. An increase in land ownership has the probability to reduce farmer's WTP by 0.041. The construction of the biogas plant requires at least a land area of 30 m^2 for the 8 m^3 BGP. The mean willingness to pay was estimated at 13 USD or 8000 FCFA. This is almost 4 times less than the monthly amount required to repay for the biogas plant in 3 years. On average, it will take approximately 11.5 years to pay for the BGP. Based on the bid distribution, it will take the farmers a minimum of 0.9 years (about 11 months) and a maximum of 18.75 years (about 18 years and 10 months) to repay the BGP.

5. Conclusion and policy recommendations

5.1. Conclusion

This study first addressed the question of whether biogas technology is an economically viable clean energy option for rural households in Cameroon. The analysis shows that biogas technology is a viable is more viable as the size of the biogas plant increases. Based on the household energy demand, the 8 m^3 biogas plants remain the most viable option for the farmers' households. The benefit-cost ratios ranged from 1.01 for the 4 m^3 biogas plants to 2.04 for the 25 m^3 biogas plants. The net present values were all positive, and the internal rate of returns were above the applied discount rate. The minimum and maximum payback periods were 2.24 and 3.37 years, respectively. Viability increased with the size of BGP. Farmers are not adequately involved in the marketing of digestate and productive use of biogas, which tends to reduce the payback period of biogas plants. As such, the profitability of the technology is influenced by the management practices of each user. Farmers prefer biogas technology over traditional fuelwood and kerosene, but

Table 6
Farmers' willingness to pay for hypothetical 8 m^3 biogas plant.

Component	Value											
Bid offered to farmer (USD)	0	8	16	32	48	64	80	96	112	128	160	Total
Number of farmers	63	64	31	12	3	1	1	2	1	1	1	180
Percentage (%)	35	36	17	7	2	1	1	1	1	1	1	100
Repayment duration (years)	0.0	18.8	9.4	4.7	3.1	2.3	1.9	1.6	1.3	1.2	0.9	

based on the average amount they are willing to pay for the 8 m^3 biogas plant, it will take 18.75 years to pay for the total cost. The distribution of the bid amounts shows that farmers will take a minimum of 0.9 years (approximately 11 months) and a maximum of 18.75 years (approximately 18 years 10 months) to repay the full cost of the biogas plant.

5.2. Policy recommendations

Based on this study, some actions can be taken at the government level to make biogas technology more economically viable and attractive to farmers. Firstly, the country needs to enforce existing extension services to improve farmers' awareness about biogas technology, select the most appropriate biogas plants, valorise digestate, and engage in the productive use of biogas. Secondly, financial incentives in the form of tax exemptions or subsidies can be provided to farmers to offset the high capital investment cost. There is a need to assist financial institutions to offer low-interest loans to finance biogas projects. This would contribute to increasing farmers' willingness to adopt the biogas plants. Finally, government regulations are needed to persuade farmers to properly manage their waste through recycling to produce biogas and ensure that the private sector actors deliver standard biogas services to the farmers.

Funding

This research was funded by the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, grant number IGA [20243111].

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Chama Theodore Ketuama: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Hynek Roubík:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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