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Cost-benefit Analysis and Financial Viability of Household Biogas Plant Investment in South Ethiopia

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Abstract

This study investigates the cost–benefit analysis and financial viability of biogas plant investment in South Ethiopia. A multi-stage sampling technique was employed to select sample households. A total of 105 adopter households were selected for household survey using a purposive sampling technique. All the households adopting biogas technology were considered. Besides, a biogas plant with 6 m^3 and 8 m^3 sizes were selected because they were the most commonly used size in the study area. Data were collected from the household survey, key informant interviews, focus group discussion and market price assessment. The installation cost took the largest share of the total cost of construction and was one of the main constraints that hindered adoption. The findings of the study indicate that the production of biogas increased household income by reducing the costs incurred for buying firewood, kerosene and chemical fertilizers. Relatively, lower plant size was more profitable than larger plant size. Installation under the subsidy scheme was more financially viable at 10% discount rate than its counterparts. Subsidy is important to enhance biogas plant investment, particularly for larger biogas plant sizes. Nevertheless, both plant sizes, installed without subsidy, had smaller NPV values and UDBP greater than 1 year, making this scenario financially less viable. Installation of low cost plants could more attract the engagement of a large number of rural households with low economic capacity. However, both plant sizes (6 m^3 and 8 m^3) are financially viable and profitable at 10% discount rate. Moreover, the profitability of biogas investment is highly sensitive to variation in discount rates, level of expenditure savings and input prices.

Keywords Biogas energy, Biogas plant size, Cost–benefit analysis, South Ethiopia

Introduction

The world today is seized with the problem of energy supply, shortage of cheap and efficient fuel resources, shortage of many other usable commodities and growing environmental problem. Fast depletion of fuels particularly oil, mass-scale of deforestation leading to a fuel wood crisis and the population explosion, all combine to emphasize the need for exploiting the unconventional sources of energy which could meet the way to improve the rural economy of the world growing numbers (Kumar et al., 2014). In developing countries including Ethiopia, over 500 million households still use traditional biomass for cooking and heating (Tolessa, 2023). In Ethiopia, 95% of national energy consumption is derived from fuel wood, dung, crop residues and human and animal power. The remaining 5% is from electricity, 90% of which is generated by hydropower (Mondal et al., 2018).

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In developing countries, women tend to bear responsibility for collecting and preparing fuel for cooking, as well as the cooking itself (Tamire et al., 2018). Households dedicate an average of 1.4 h a day collecting fuel, a burden born mainly by women and children. Moreover, the loads that they carry can have an impact on their physical well-being; in Africa, women carry loads that weigh as much as 25–50 kg (UNEP (Wassie & Adaramola, 2021). The use of candles, kerosene and other polluting fuels for lighting has serious implications for health. Solid biomass in a three-stone fire, which is the most common traditional cooking method, releases polluted air which is cause for health, especially for women and children (Dumga & Goswami, 2023).

The interest of having access to modern and renewable energy in Ethiopia has been increasing as the rural community is suffering from the energy crisis and ever increasing cost of chemical fertilizers and kerosene (Mengistu et al., 2016; Sime et al., 2020). The use of chemical fertilizers becomes dominant and its volume is growing up annually with unaffordable prices (Mengistu et al., 2016). On the other hand, the price of kerosene has also ever increasing (Sime et al., 2020). These problems can be improved using biogas technology (Fentie & Sime, 2022).

Furthermore, biomass fuel is becoming scarce and household productivity is being affected by the reallocation of time and labour from yield bearing activities of collection of biomass energy, which have led to reduced rural economy (Mekonnen, 2020). Time saved through access to bio-energy like biogas can be redirected towards education, social and family activities and economic opportunities (Song et al., 2023). Due to the ongoing deforestation and shortage of firewood, households need to look for other energy sources where a large number of people use residues from agriculture (straw, manure) instead. However, both straw and manure also have a function in agriculture for soil improvement (Bewket, 2012). The deployment of biogas energy as an alternative energy source can have the potential to fill the gap in the energy needs of the rural community if it is effectively managed and appropriately utilized (Kelebe et al., 2017).

Biogas is composed of methane (40–70%) and carbon dioxide (30–60%) as a combustible gas produced by the action of methanogenic bacteria (Demirbas & Balat, 2009). It is a naturally occurring by-product of decaying plant and animal material while bio-slurry is its by-product. Biogas is an emerging bio-energy technology in the rural areas of Ethiopia through biogas development program for potential households (Gabisa & Gheewala, 2019). The history of biogas energy use in Ethiopia is relatively old. Biogas was first introduced in Ethiopia in to Ambo Agricultural College in 1957/58 to generate the energy required for welding agricultural tools and other equipment (Abadi et al., 2017). Since then efforts have been made by the Government and NGOs to introduce and disseminate the technology in different parts of the country. However, the rate of dissemination was very sluggish till the launching of the National Biogas Programme of Ethiopia (NBPE) in 2008.

In the previous time, the promotion of biogas plant in Ethiopia was mostly concentrated on household, research institution and farmers association. The dissemination strategy was also through subsidy with limited participation of the beneficiaries in the implementation of the programs. On the consumption side the approach was not commercial and the promotion of the technology owned by the governmental and donor organization (Shallo et al., 2020). Limited success in promoting improved energy sources, such as biogas, in rural areas of developing countries has been partly blamed on insufficient understanding of household energy use patterns (Gwavuya et al., 2012).

Most of the Ethiopian rural households are involved in subsistence farming that integrates agriculture and animal husbandry. Thus, domestic biogas could theoretically not only foresee the need for cooking energy, but also provide a good source of organic fertilizer (Mengistu et al., 2015). Therefore, biogas energy is an appropriate technology for rural community in Ethiopia. It has multiple benefits such as the use of clean energy for cooking and lighting, the use of bio-slurry as organic fertilizer and income generation through reducing the use of purchasing fuels (firewood, charcoal and kerosene) and chemical fertilizers (Bewket, 2012; Erdogdu, 2008). Technical issues like the availability of feedstock (water and cow dung), and the existence of conducive temperature for its operation make Ethiopia a country suitable for biogas utilization and dissemination (Eshete et al., 2006). In conformity, Ethiopia has launched its National Biogas Program (NBPE) in 2009, for dissemination of domestic biogas technology through a subsidy modality for at least one million households. Netherlands Development Organization (SNV)—Ethiopia is supporting the implementation of this market-based domestic biogas programs in different countries in Asia and Africa with a view to establish a commercially viable biogas sector (Gwavuya et al., 2012).

Economic viability refers to an estimator that seeks to maximize the effectiveness of financial viability. Financial viability is state the profitability of biogas plants primarily from monetary surplus gained from utilizing biogas and bio-fertilizer in relation to the cost of the plants. Profitability is achieved when income is bigger than expenses. When making economic decisions, the option with the highest profitability is usually chosen (Sarker et al., 2020).

Economic cost–benefit analysis is the most efficient and widely used tools for measuring whether any investment would be beneficial or not, along with their environmental and social concern (Chakrabarty et al., 2013; Gwavuya et al., 2012).

The cost benefit analysis process estimates the benefits and costs of an investment for two reasons: 1.To determine if the project is viable; if it is a good investment 2. To compare one project investment with other competing projects, to determine which is more feasible. In studying the cost–benefit analysis and financial viability of the biogas plant investment, incomes generated in terms of a monetary value encompass: expenditure saved due to the substitution of other energy sources with biogas, income generated from the sale of biogas (when applicable), replacing the cost of using chemical fertilizer by bio-slurry, income generated from the sale of bio-slurry (when applicable), time saved for collecting and preparing previously used fuel materials (when applicable), time saved for cooking after utilizing biogas energy (when this time can be used to generate income), improved indoor air quality and consequent reductions in medical expenditure for respiratory infections. This is because the biogas energy generated and bio-fertilizer produced can alleviate poverty by improving health conditions, increasing crop productivity and saving working time and reducing burden on women and children (Wattanasilp et al., 2021).

On the other hand, the most important cost associated with biogas plant installation is manufacturing, acquisition costs (production costs), or capital costs. The production cost includes all expenses which are necessary for the installation of biogas plants. It includes land, excavation work, cost of material for building biogas plant (cement, bricks, gravel and stones), gasholder, displacement pit, gas stove, piping system and dung storage system. Operation costs mean running costs that paid for feeding raw dung or foregone revenue from the sale of raw dung (Chakrabarty et al., 2013). On the other hand, this study assumes that the installation of plants has both costs and incomes; installation and maintenance service demand financial costs, but reduces costs for purchasing firewood, kerosene and chemical fertilizers, which are regarded as benefits or incomes.

Investment of biogas plants for improving energy security and bio-slurry for increasing agricultural productivity are the two most important purposes behind domesticating biogas technology in rural Ethiopia. Besides that the technology is important for improving environmental health, reducing deforestation and mitigating greenhouse gas emission. The biogas produced energy is renewable and more sustainable which can help to provide incessant supply of socio-economic benefits. However, there are scanty studies in dealing with the investigation of the cost–benefit analysis and financial viability of biogas plant investment. The economic potential of the technology has been largely remained indefinable and households are mostly seen to be doubtful to invest in it. To increase the production and also use of biogas, the return from the biogas plants should be evaluated whether it is profitable, and the investor households should be confident on it. Thus, this study is initiated to evaluate the profitability of current and future biogas plants in Southern Ethiopia.

Methodology

Description of the study area

Aleta Wondo district, the study area, is one of the 19 districts in the Sidama Region in southern Ethiopia. It is administratively divided into 27 rural *Kebeles* [1], with the total of 32,309 households. It is located at 337 km to the south of Addis Ababa, the country's capital city and 62 km from Hawassa, the capital city of the regional state. It is located between 6^0 35′and 6^0 40′ N latitude, and between 38^0 23′ and 38^0 26′ E longitude. According to the Central Statistical Agency (CSA) of Ethiopia, Aleta Wondo has a land area of 567.2 km^2 with a population of 191,592 of whom 97,364 are males and 94,228 are females while 175,055 rural and 16,537 are urban population (CSA, 2013) (Fig. 1).

Sampling design and sample size

A multi-stage sampling technique was used for selecting sample households to be surveyed. First, the Aleta Wondo district was selected purposively for being the home of the largest number of biogas investments during the survey time. Second, only three *kebeles* were selected purposively from the 27 rural *kebeles* based on the availability of biogas plants as well as experience in biogas energy and bio-slurry generation and utilization. The rest *Kebeles* have not installed biogas plants. The total numbers of installed biogas plants in the three selected kebeles were 105. The respective *Kebele* Executive Energy Offices provided the list of biogas adopter households. Thus, all adopters (who their biogas plants are functioning) in the study *kebeles* were used as sampling units.

Data sources and collections

Primary data were collected through household questionnaire survey, key informant interviews, focus group discussion and field observation in 2017. The data were collected in three seasons: from July to August in which production and temperature is low, from September

[1] *"Kebele" is the smallest administrative unit in an Ethiopian Administrative Structure.*

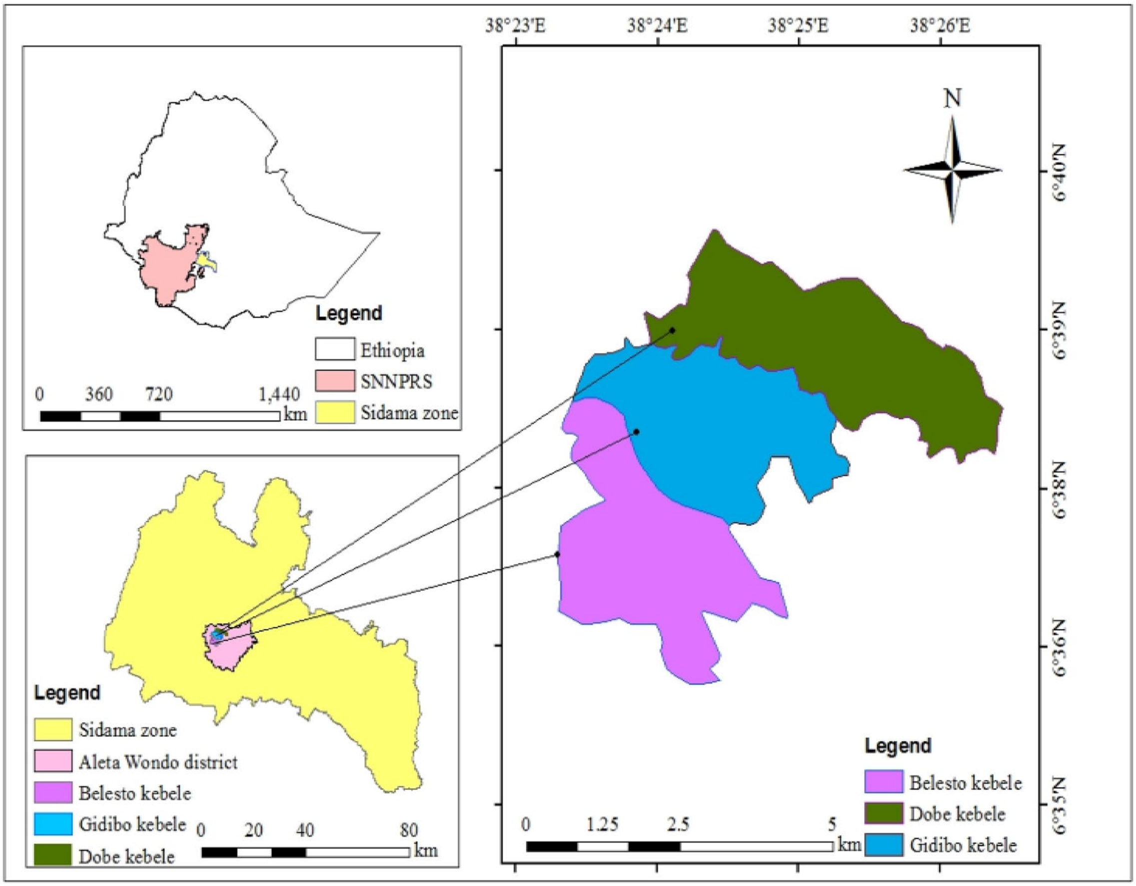

Fig. 1 Physical map of the study area

to November in which production and temperature is medium, and in December to March in which production and temperature is high. The average of these three seasons has been used to evaluate the return of biogas plant. Because of average of the three seasons is rest in ranges of the average of fermentation temperature of biogas which is between 27 and 35 °C. Seasonal variations in air temperature significantly affected the fermentation rate and biogas production (Deepanraj et al., 2015). Open ended and closed ended semi-structured questionnaire (for personal household interview) and checklists (for key informant interview, focus group discussion and field observation) were used for collecting quantitative and qualitative data. Researchers, and experienced and skilled data collectors together collected the data.

The questionnaire was administered to the 105 biogas adopter households. Three experienced and knowledgeable individuals were used as key informants in each *Kebele.* They were biogas adopters, *Kebeles'* Development Agents, and energy technicians. Twelve participants in each *Kebele* were used as focus group discussants. They were adopter households being grouped into men-headed and female-headed adopter households separately. The gender classification was to enable free discussion to avoid cultural influences of men over women. Each of the two groups had six members. Field observations were also carried out with both formal and informal discussants.

Socio-economic characteristics of respondents

Eight important characteristics of respondents were considered for their influence with cost–benefit analysis and finical viability of Biogas technology. These characteristics include sex of household head, age of household head, education level of household head, household size, land holding size, household livestock holding size, household annual income and availability of water sources. The national average size of household is 4.7 people per household Population (CSA, 2013). This average household size in the study area is appeared to provide adequate labor force for the regular operation of biogas plant. The Ethiopian economically active was 15–64 years (CSA, 2013). This suggests that farmers, regardless of gender, are in their middle and productive years. The average level of education of household heads is 5.86 grades (CSA, 2013). To establish biogas technology as a viable and long-lasting option, it is quite essential to educate the people about the socio-economic, health and environmental benefits of the technology (Landi et al., 2013).

The size of livestock population in general and cattle population in particular is one of the most important factors that determine the availability of sufficient dung for the successful operation of biogas plants. Cattle dung is the primary input for biogas plants in Ethiopia and in the study area. Consequently, the NBPE has targeted households with a minimum of 4 heads of cattle. A 4 heads of cattle are supposed to produce a minimum of 20 kg dung daily, which is needed to feed the minimum size (4 m^3) biogas plant of the programme (Eshete et al., 2006). Households having higher income are more likely to adopt biogas technology than those with lower income due to the high cost of installation (Iqbal et al., 2021).

The average total land holding size of adopter households is 1.76 ha, which was sufficient for biogas plant installation. According to Martinát et al. (2016), a quarter an acre (0.101 ha) is adequate even for a large biogas plant installation whatever the size and the mode of plant. Despite the use and management of household energy is primarily the duty of women in rural community of Ethiopia, female-headed households have lack of time for gathering information about new technology due to women are involved in many responsibilities in the home such as cleaning, cooking and child care (Eshete et al., 2006). Water supply is another critical requirement for biogas technology because it serves for both livestock keeping and biogas plant operating. An equal amount of water and/or urine needs to be mixed with cow dung before it is fed into a biogas plant. While Ethiopia has relatively abundant water resources (estimates of renewable annual groundwater per year range from 13.5 to 28 billion m^3), the distance of water source from homestead are challenging the adoption of this technology as national level (Merga et al., 2022).

Methods of data analysis

Data collected through survey

The collected raw data were coded, edited and organized using a Microsoft Excel. Then, the organized data were entered and analyzed using IBM SPSS Statistics version 20 at $\alpha = 0.05$. The data were analyzed using analytical methods such as descriptive statistics and economic analysis. The monetary benefits of household biogas plant were analyzed by paired-samples *t* test. The cost of installation and maintenance service of biogas plants were analyzed using mean. Whereas data collected through key informant interviews, focus group discussion and field observations were transcribed and then broken into themes and subthemes.

Estimation of costs and benefits

For monetizing the cost and benefits, this study follows the guidelines of the World Health Organization (WHO, 2006). The costs and benefits associated with biogas plants were quantified and estimated on the basis of valuation of kerosene, firewood and chemical fertilizer consumptions. The cost of locally available material was valued at the local market price, while those of tradable components were valued at the local retail market prices. The annual maintenance cost was estimated as follows:

$$M_c = 0.04C, \tag{1}$$

where M_c is maintenance cost, C is the total investment cost and following Kandpal et al., (1991), a figure of 0.04 or 4% of the investment cost is assumed to be adequate for the maintenance cost because the approximate cost of these and other routine maintenance costs have been shown to be roughly proportional to the investment costs of the plant capacity.

In this study, the monetary benefits of biogas plants were computed only for the saved costs on firewood and kerosene substituted by biogas energy and saved costs on chemical fertilizer substituted by the bio-slurry. This is because there is no direct selling of biogas energy and bio-slurry in local markets. The time saved due to biogas energy use was not estimated owning to the fact that the time saved as a result of the redundant wood collection and cooking practices is categorized as an economic value (shadow prices) and is not monetary benefit (Laramee et al., 2018).

The firewood consumptions per household were gathered in a unit of bundle per week, and later converted into kg per week and then into kg per year. It was, thus, estimated by the following the formula of Bala and Hossain (1992) as:

$$\mathrm{TAB_f} = 52.143(\mathrm{WF_{cb}} - \mathrm{WF_{ca}})\mathrm{P_{fw}}, \tag{2}$$

where $\mathrm{TAB_f}$ is the total annual monetary benefits from firewood saving, 52.143 refers to 52.143 weeks per year, $\mathrm{WF_{cb}}$ is the weekly firewood (kg) consumption before adopting biogas technology, $\mathrm{WF_{ca}}$ is the weekly firewood (kg) consumption after biogas technology adoption per household and P_{fw} is the price of firewood per kg at the time of collection.

Data related to kerosene consumption were considered in terms of number or a unit of bottle consumed per week and later was converted to litre (l). Consequently, the cost saved from kerosene consumption was calculated according to Bala and Hossain (1992):

$$\mathrm{TAB_k} = 52.143(\mathrm{WK_{cb}} - \mathrm{WK_{ca}})P_k, \quad (3)$$

where $\mathrm{TAB_k}$ is the total annual monetary benefits from kerosene saving, 52.143 refers to 52.143 weeks per year, $\mathrm{WK_{cb,}}$ is the weekly kerosene consumption (litre) before adopting biogas technology, $\mathrm{WK_{ca,}}$ is the weekly kerosene consumption (litre) after adopting biogas technology per household and P_k is the price of kerosene per litre at the time of data collection.

Following Biswas and Lucas (1997), the monetary benefit of bio-slurry was estimated using existing cost of chemical fertilizer consumption and was computed as follows:

$$\mathrm{TAB_s} = (\mathrm{AC_{ha}} - \mathrm{AC_{ha}})P_{\mathrm{ch}}, \quad (4)$$

where $\mathrm{TAB_s}$ is the total annual benefits from bio-slurry consumption, $\mathrm{ACh_b}$ is the annual amount of chemical fertilizers consumption per household before adopting biogas technology, $\mathrm{ACh_a}$ is annual amount of chemical fertilizers consumption per household after biogas adoption and $p_{\mathrm{ch,}}$ is the official price of chemical fertilizers (both DAP and Urea) at the time of data collection.

By combining the above formulae, the total annual monetary benefit of household biogas plants (TAB) was estimated as follows:

$$\mathrm{TAB} = \mathrm{TAB_f} + \mathrm{TAB_k} + \mathrm{TAB_s}. \quad (5)$$

Economic tools like benefit–cost ratio (BCR), undiscounted payback period (UPBP) and net present value (NPV) were employed for the economic analysis of the biogas plant installation and operation. A fixeddome biogas model (local name *SINIDU*, meaning "ready"), and 6 m^3 and 8 m^3 biogas plant sizes were selected for financial analysis. This is because they were the most commonly used model and size in the study area.

Undiscounted payback period (UPBP)

The payback period is the period of time over which the accumulated cash flows will equal the initial outlay, i.e. payback period is the amount of time that takes for a project to recover its initial investment. A short payback period may be desirable to ensure that the capital expenditure is quickly recovered and repatriated so that at least the initial investment will have been recovered. In this study, the annual net revenue was assumed to be constant. The UPBP was, therefore, used in the analysis because a constant rate is suitable for computations were annual benefits and maintenance costs are assumed uniformly over the useful economic life of a plant. Thus, the UPBP was calculated as follows:

$$\mathrm{UPBp} = \frac{\mathrm{CI}}{\mathrm{Ap}}, \quad (6)$$

where CI is total installation costs, AP is annual profit which is annual monetary benefits from biogas technology adoption.

Net present value (NPV)

According to Mmopelwa (2006), NPV is given by the following formula:

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^{\mathrm{t}}}, \quad (7)$$

where B_t is the benefit obtained from the biogas plant installation (biogas, bio-slurry) in each year, C_t is the cost in each year, t is the expected useful economic life of a fixed-dome biogas plant from the present; $t = (1, 2 \ldots 15)$ and r is the discount rate (which is applied to anticipated costs and benefits of a project over the life span of the project to convert the value of a return in the future into today's value and to ensure that future project returns are not being over- or under-estimated in today's value). B_t and C_t were assumed uniformly over the expected useful economic life of biogas plants and discounted across all year. A useful economic life of a fixed-dome plant was assumed to be 15 years. Biogas investments in the study district are run by the NBPE and SNV—Ethiopia. This both subsidizer organization considered the length of time to be 15 years. This was based on the quality of masons and materials used in the study area. A discount rate of 10% was assumed based on the recent minimum lending interest rate for long-term, which was provided by the Development Bank of Ethiopia (DBE) to farmers' association (Authority, 2012). An investment is profitable when its NPV is greater than zero, the bigger NPV; the better the investment will be Sinha & Kandpal, 1990).

Benefits–cost ratio (BCR)

The BCR is the ratio of benefits per unit of cost and was estimated (Rahman and Kholilullah, 2017):

$$\mathrm{BCR} = \frac{B_t/(1+r)^t}{TC_t/(1+r)^t}, \quad (8)$$

where $\mathrm{TB_t}$ is the total financial benefits obtained from the biogas plant (biogas, bio-slurry), $\mathrm{TC_t}$ is the total costs (installation costs and annual maintenance costs) of biogas plant. $\mathrm{TB_t}$ and $\mathrm{TC_t}$ were discounted only at the initial year of investment ($t = 1$) because it is used to measure the present value of returns per money invested.

Table 1 Estimation of installation costs of household biogas plants

Inputs (materials and labor) cost	Quantity of materials and labor size required for installation		Unit price (ETB)	Total cost of material and labor (ETB) required for installation	
	6 m^3	8 m^3		6 m^3	8 m^3
A. Civil construction cost					
1. Cement (bags, 50 kg)	11	16	135	1485	2,60
2. Sand (barrows)	12	18	75	900	1350
3. PVC pipe (6 m length and 70 mm diameter with its elbow)	2	4	150	300	600
4. Galvanized steel (dome gas pipe), 1.5 m length and 60 mm diameter with its elbow		1	345	345	345
5. Iron bar (6 m length and 8 mm diameter with binds)	7	11	165	1155	1815
6. Transportation cost				210	240
Subtotal				4395	6510
B. Labor cost					
1. Mason cost (paid by adopters)				1300	1600
2. Grave worker cost (barrows)	12	15	90	1080	1350
Subtotal				2380	2950
C. Total cost (*A* + *B*)				6775	9460
D. Subsidy					
1. Cost of supply line				2420	2420
2. Mason (subsidized by NBPE)				3580	3580
Subtotal				6000	6000
E. Total installation cost (*C* + *D*)				12,775	15,460

The average installation costs vary among households due to differences in plant size and costs of materials and labor required. All figures in the table are rounded off to the nearest possible

Sensitivity analysis of selected variables

Sensitivity analysis is required to identify those input variables that are important in terms of contributing to predict the output variation and in quantifying how changes in the values of input parameters alter the values of the output variable. Sensitivity of variables is often a non-linear, complex and unsteady process, so it is difficult to derive a linear formula to represent the influence of all variables in the process. Furthermore, simplifying the nature of analysis using a linear model would lead to unreliable results in practical applications of this research. Therefore, the neural network is used as an alternative way of sensitivity analysis because it considers linearity and non-linearity. It is fast, accurate, viable and efficient alternative against the traditional techniques of sensitivity analysis (Costa et al., 2013).

In cost–benefit analysis, the result is always influenced by several uncertainties. Sensitivity analysis helps to know how sensitive the NPV is to change in those uncertain factors (key variables) Lilburne & Tarantola, 2009; Gwavuya et al., 2012). Therefore, sensitivity analysis was conducted to quantify the impact of change in key (selected) variables on the estimates of NPV to determine the financial stability of household biogas investment in the study area. In this study, the key variables were grouped into three sensitivity scenarios: input price scenario, the level of expenditure saving scenario (a saving of firewood, kerosene and chemical fertilizer) and discount rate scenario.

Results and Discussion

The economic benefits of biogas technology such as time saved (for biomass demand, cooking, cleaning utensil and chicken), reduced cost of weeding, employment generation and saved disposal cost have not been considered due to their absence of market price and the study has focused only on the monetary benefits of biogas technology in cost savings of kerosene, firewood and chemical fertilizers consumption; due to they have market prices. Cost of biogas investment includes installation, operational and maintenance costs which may have not market value, nevertheless the study only focused on the costs of market price resources.

There was no actual measurement for gathering the quantifiable data (costs and benefits of biogas plant) and information because it was a survey of the households. Thus, the recall method was used, which may not be accurate. The results of the study, therefore, need to

Table 2 Total investment costs of biogas plants

SN	Cost type	Biogas plant size	
		6 m^3	8 m^3
1	Total installation cost (ETB)	12,775	15,460
2	Annual maintenance cost (ETB)	511	619
	Total investment cost (ETB) [1 + 2]	13,286	16,079

Table 3 Weekly firewood consumption before and after biogas plant installation

Variable	Plant size	Category	Minimum	Maximum	Mean ± SD	*t* value	*p* value
Firewood (Kg)	6 m^3	Before adoption	64	128	103.53 ± 37.50	9.135	0.000[a]
		After adoption	32	64	51.76 ± 15.21		
	8 m^3	Before adoption	96	128	107.29 ± 36.53	9.926	0.000[a]
		After adoption	32	64	52.39 ± 15.04		

[a] Represents1% level of significance

be understood in this context, and be regarded as more indicative than representative.

Costs related to household biogas plant system

The cost of household biogas investment consisted of installation and operational costs (Table 1). The installation cost covers costs for purchasing the materials used for bio-digester construction, such as cement, bricks, sand, gravel work and PVC planks. The operational costs, whereas covers costs related to maintenance and other routine labour for feedstock preparation and feeding the biogas system. While operational costs are mostly related to costs incurred for maintenance service. In accordance, the total costs of the most commonly used fixed-dome household biogas plants of 6 m^3 and 8 m^3 biogas plant sizes were computed as total installation costs (Table 1) and maintenance costs (Table 2). The installation cost is expensive for most households. Hence, loans and subsidies are arranged. The survey data and secondary data obtained from Aleta Wondo District Water, Mine and Energy Office (AWDWMEO) (AWDWMEO, 2017) showed that all biogas owners acquire loans from the OMO Microfinance Institution (with a repayment period of 2 years and 15% interest rate). The loan was subsidized with the help of the National Biogas Programme of Ethiopia (NBPE). Since 2010, AWDWEMO has been endorsing a subsidy amounting ETB 6000 for each household biogas plant regardless of plant sizes. Out of the subsidies, an amount of ETB 2,420 was the cost of supply line used for purchasing a biogas stove, biogas lamp with its accessory, valves (main gas, drainage and gas tap) and connectors; while the remaining ETB 3,580 was paid for biogas mason. The same subsidy was provided equally for all households and plant sizes. However, the payment for masons varied with plant sizes, ETB 1300 for 6 m^3 and ETB 1600 for 8 m^3. The rate had been uniform from 2010 to the time of the execution of this study. This payment would better change with time.

As the plant size increased, the installation cost also increased proportionally. There was a proportional increase in cost between plant size and installation cost (Table 2). This is consistent with Chakrabarty et al., 2013) that as the biogas plant size increases, so is the cost per m^3 of plant. Though the cost of inputs is naturally increasing, the present installation cost is so much close to same cost calculated during the 2008 baseline survey of NBPE which was about ETB 13,000 for 6 m^3 size (Eshete et al., 2006). The reason might be that installation depends on local construction materials and households hire no labour from outside. They use household members for executing labour related works, including excavation work. Thus, the use of local material with no external costs and the lack of labour wages are the factors that have regulated inflation in installation costs over time.

Monetary benefit from firewood consumption replacement with biogas investment

Depending on accessibility and choices, households' used a variety of energy sources. These energy sources were firewood, crop residues, kerosene and biogas energy. Firewood was utilized by the entire sample households for cooking. A few sample households still sell firewood while others purchase trees or logs for firewood. According to Haile (1989), on average, one bundle of firewood weights 32 kg. On average, the selling price of one bundle of firewood in the area was about ETB 46.97 (at local retail market, January 27, 2017, when 1 USD = 22.46, at the National Bank of Ethiopia (NBE)). Hence, the price of 1 kg firewood at the time of data collection was ETB 1.4678125 ≈ 1.47.

The weekly average firewood consumption of adopter households before adoption was 103.53 kg per household (HH) for 6 m^3 and 107.29 kg per HH for 8 m^3 plant sizes (Table 3). Whereas, it was 51.76 kg firewood per HH

Table 4 Weekly kerosene consumption before and after biogas plant installation

Variable	Plant size	Category	Minimum	Maximum	Mean ± SD	*t* value	*p* value
Kerosene (L)	6 m^3	Before adoption	0.67	2.00	1.63 ± 0.68	17.202	0.000[a]
		After adoption	0.00	0.00	0.00 ± 0.00		
	8 m^3	Before adoption	1.00	2.33	1.72 ± 0.67	18.443	0.000[a]
		After adoption	0.00	0.00	0.00 ± 0.00		

[a] Represents 1% level of significance

Table 5 Annual chemical fertilizers consumption before and after biogas plant installation

	Plant size	Category	Minimum	Maximum	Mean ± SD	*t* value	*p* value
DAP used (kg)	6 m^3	Before adoption	75	250	185.24 ± 66.659	12.302	0.000[a]
		After adoption	25	100	30.29 ± 17.972		
	8 m^3	Before adoption	100	275	198.57 ± 75.466	21.255	0.000[a]
		After adoption	37.5	125	38.45 ± 8.614		
Urea used (kg)	6 m^3	Before adoption	50	175	108.33 ± 53.334	19.636	0.000[a]
		After adoption	6.25	75	17.68 ± 18.272		
	8 m^3	Before adoption	75	200	140.71 ± 49.669	21.458	0.000[a]
		After adoption	12.5	100	22.02 ± 124.608		

[a] Represents 1% level of significance

for 6 m^3 and 52.39 kg firewood per HH for 8 m^3 plant sizes, after adoption. As a result, households installing 6 m^3 and 8 m^3 were able to save 2,699.44 kg firewood per HH and 2,862.65 kg firewood per HH, respectively, annually (Table 3). In terms of annual monetary benefit, the 6 m^3 and 8 m^3 helped the earning of, respectively, ETB 3,968.18 per HH and ETB 4208.09 per HH, after adoption. Previous studies conducted in rural Ethiopia reported similar findings that adoption of biogas technology enables saving various sizes of firewood consumption and generates incomes (Gwavuya et al., 2012). The amount of firewood saved and income generated vary from localities to localities depending on the type of fuel available and choices, as well as the availability of markets and nature of market prices. For instance, biogas adopter households in the study area did not use charcoal and kerosene stove for cooking; they rather mostly use firewood for cooking.

Monetary benefit from kerosene consumption replacement with biogas energy investment

In the study area, households use kerosene lamp for lighting purpose. Data on kerosene consumption were counted in a unit of bottle per week and was later converted to litre (l), 1 bottle ≈ 0.33 l or 3 bottles ≈1 L. The local retail market price of 1 L of kerosene was ETB 27 (when 1 US$ = 22.46 Birr, January 27, 2017). Adopter households had completely replaced kerosene consumption by biogas energy. Thus, before installing 6 m^3 biogas plant they have used 0.67 L in minimum and 2 L in maximum. However, after adopting biogas they have completely used biogas lamp for light instead of kerosene. Accordingly, they were able to save about 84.99 L of kerosene per HH (there are 52.143 weeks per year according to Ethiopian calendar; thus, 1.63 L multiplied by 52.143 weeks = 84.99 L/HH) due to adopting 6 m^3 and 89.69 L kerosene per HH due to adopting 8 m^3, annually (Table 4). Therefore, the use of 6 m^3 and 8 m^3 plants enabled generation of the annual income ETB 2,294.73 per HH and ETB 2,421.63 per HH, respectively. Results from a previous study conducted in rural Ethiopia reported similar findings that biogas energy soundly replaces the use of kerosene and generates different amount of incomes (Mengistu et al., 2016). The amount of kerosene that can be replaced and income generated show spatial and temporal variations.

Monetary benefit obtained from the cost saved from chemical fertilizers purchased

The price of 100 kg of DAP and 100 kg of Urea was ETB 1486 and ETB 1374, respectively, at the time of data collection. The amount of bio-slurry generated from both plant sizes was found to be inadequate to cover all farmland. Thus, adopters were seen to still use DAP and Urea to cover farmlands that had not been covered with bio-slurry. Adoption enabled the saving of 154.95 kg (185.24–30.29 kg) per HH per year and 160.12 kg (198.57–38.45) per HH per year of DAP consumption from 6 to 8 m^3

Table 6 Summary of annual monetary benefits from household biogas plant installation

Variable	Biogas plant size	
	6 m^3	8 m^3
A. Annual monetary benefit from biogas energy (ETB)		
1. Monetary benefit from replacing firewood consumption with biogas energy (ETB)	3968	4209
2. Monetary benefit from replacing kerosene consumption with biogas energy (ETB)	2295	2422
B. Annual monetary benefit from bio-slurry (ETB)		
1. Monetary benefit from saving cost for buying chemical fertilizer, DAP (ETB)	2303	2379
2. Monetary benefit from saving cost for buying chemical fertilizer, urea (ETB)	1245	1630
Total annual monetary benefit from biogas plant installation (ETB) [$A+B$]	9811	10,640

plants, respectively (Table 5). Accordingly, the annual monetary benefit when DAP was substituted with bio-slurry was ETB 2, 302.56 per HH from 6 m^3 and ETB 2,379.38 per HH from 8 m^3 plants (Table 5). In this regard, adopter households DAP consumption before and after adoption of both plant sizes were significantly different ($p<0.01$). The amount of urea saved by adopter households was 90.65 kg (108.33–17.68 kg) per HH per year for 6 m^3 and 118.69 kg (140.71–22.02 kg) per HH per year for 8 m^3 plants (Table 5). Accordingly, the annual monetary benefit adopters obtained from the cost spent on urea when substituted with bio-slurry was ETB 1,245.53 per HH and ETB 1,630.80 per HH for 6 m^3 and 8 m^3 plants, respectively. This implies that 8 m^3 plants are more beneficial than 6 m^3 plants because as the size of plant increases the amount of bio-slurry also increase. Similar findings were reported (Fentie & Sime, 2022; Tekle & Sime, 2022) that adoption of biogas technology enables substitution of chemical fertilizers and generation of incomes. The amount of substitutions made and monetary benefits generated appear to depend on multiple factors, such as the amount of bio-slurry generated and its effective use as a quality source of bio-fertilizer, the price and type of the replaced chemical fertilizers, sizes farmland owned by adopter households and level of households' awareness. In addition to the energy aspects of biogas technology, the bio-slurry aspect of the technology need sound attention and promotion strategies. For successful biogas program in Ethiopia, both aspects of the technology, biogas energy and bio-slurry, should be promoted as an integral strategy of ensuring rural energy and food security. The technology's major outputs are ideal in augmenting the prevailingly practiced mixed crop-livestock farming system in rural Ethiopia (Table 6).

Financial viability of household biogas plants

The financial estimation in this study considers only the costs and monetary benefits of the biogas investment, not including some other external costs and benefits (Table 6). The survey result showed that all installed biogas plants were subsidized. For this reason, the financial viability of households' investment into biogas plant installation was evaluated as with a subsidy (base assumption) and without a subsidy. Under without subsidy situation, no external financial incentive was incorporated into the calculation of a biogas plant. Without subsidy estimation of a biogas plant offered the actual cost to be incurred for installation of a biogas plant. Such an arrangement seems to attract interested households in investing in biogas installation. Particularly, households, who for financial limitation, could not adopt will be potential beneficiaries of subsidies. While with the subsidy estimation of a biogas plants provided that a subsidy plays vital role in increasing the adoption rate and in attracting low-income households to biogas technology adoption. Hence, for the financial estimation of a biogas plant installation with a subsidy, the finance allocated (ETB 6000) was subtracted from the calculated cost of installation for each biogas plant. As the results of undiscounted payback period, net present value (NPV) and benefit–cost ratio (BCR) indicates that 6 m^3 biogas plant was financially profitable than 8 m^3. Because of the payback period of 6 m^3 is shorter than 8 m^3, the net present value (Valued in Birr) of 6 m^3 is greater than 8 m^3 and benefit–cost ratio of 6 m^3 is greater than 8 m^3.

Undiscounted payback period (UPBP)

Biogas plant with subsidy in both sizes repaid the original cost of investment in a shorter period than biogas plant

Table 7 The results of UPBP with and without subsidy of biogas plants

SN	Undiscounted	Payback period (years)	
		6 m^3	8 m^3
1	With subsidy	0.73	0.97
2	Without subsidy	1.38	1.59

Table 8 The results of NPV with subsidy and without subsidy of biogas plants

SN	Scenario	Net present value(ETB)	
		6 m^3	**8 m^3**
1	With subsidy	56,508	55,674
2	Without subsidy	51,053	50,219

Table 9 The results of BCR with subsidy and without subsidy of biogas plants

SN	Scenario	Benefit–cost ratio (BCR)	
		6 m^3	**8 m^3**
1	With subsidy	1.34	1.10
2	Without subsidy	0.74	0.64

without subsidy. Investing in 6 m^3 biogas plants with subsidy recovered the installation cost within 0.73 years, while the 8 m^3 plants recovered the installation cost within 0.97 years (Table 7). This implies that a household with a 6 m^3 plants would take a few months to recover the original cost of investment through the annual net cash revenues it generates than the 8 m^3 plants.

Under the assumption of without subsidy, the payback period of 6 m^3 biogas plant was shorter than 8 m^3 biogas plants (Table 7). However, both plants take a long period when compared with a subsidized scheme to recover the initial investment costs, which were 1.38 years for 6 m^3 and 1.59 years for 8 m^3 biogas plants. This justification only implies the comparison of biogas investment with subsidy and without subsidy. By considering subsidy arrangement to biogas adopters, based on the UPBP results, the 6 m^3 plant with a shorter period was more financially viable than the 8 m^3 plants. This implies that as the size of the biogas plant increases, the UPBP also increases. The 8 m^3 biogas plants had higher installation costs than the 6 m^3 plants.

Net present value (NPV)

The NPV is a way of comparing the present and future values of cash flow using discount rate and a time constraint. The NPV is used as the indicator to measure the balance of benefits and costs. It is the most appropriate one as this method allows comparing benefits and costs arising during its life cycle (lifetime). Under both assumptions, the NPV results for 6 m^3 and 8 m^3 biogas plant sizes were turned out to be positive (Table 8). Positive NPV means that the biogas investment is preferable, and profitable for further investment. It means that the cost invested for the respective plant size was smaller than the income generated. The NPV for 6 m^3 biogas plant was ETB 56508 and ETB 55674 for 8 m^3 under the assumption with subsidy while the NPV under the assumption without subsidy was ETB 51053 for 6 m^3 biogas plants and ETB 50219 for 8 m^3 plants (Table 8). This implies that a 6 m^3 biogas plant; under both assumptions with and without subsidy, would be more sensitive to changes in financial parameters and profitable than the 8 m^3 size. The biogas investment without subsidy in both 6 m^3 and 8 m^3 plants are less viable than of biogas investment with a subsidy (Table 8). This implies the profitability of biogas investment and indicates the role of subsidy in the power of adoption and economic benefits. Such economic performance of biogas plants is an important factor for households who consider biogas plants as an investment.

This result is in line with Gwavuya et al. (2012) that small size biogas plants in Ethiopia were more profitable than large size plants. Gebrezgabher et al. (2010) showed that under the assumption with subsidy, biogas users in Netherlands obtain better financial results compared to assumption without subsidy. However, under both assumptions biogas investment yields positive NPVs. Households largely collect their own fuel. Nevertheless, by investing in biogas plants, they could save time and energy, and have a supply of bio-slurry that can be used as fertilizer in agricultural production. A cost–benefit analysis of biogas plants yields positive NPVs for households collecting their own energy sources. Even higher NPVs are obtained for households purchasing all of their energy needs. These households stand to gain significantly from the financial benefits of energy cost savings with biogas technology adoption. These financial benefits are highly dependent on bio-slurry being effectively used as a source of fertilizer, with the price of the replaced chemical fertilizers and fuel sources as well as saving costs related receiving health services. These financial benefits hold under the assumption of subsidies that biogas plants are highly subsidized under the existing scheme.

Benefit–cost ratio (BCR)

The BCR was used to measure the present value of returns per ETB invested. The financial analysis of BCR, under the assumption with subsidy, was found to be 1.34 and 1.10 at 10% discount rate of 6 m^3 and 8 m^3 plants, respectively (Table 9). This means that the investment in biogas plant by ETB 1.0 would provide a return (profit) of 34 cents for 6 m^3 and 10 cents for 8 m^3 plants. Therefore, the use of biogas plant was more viable as the cost associated with it is outweighed by the benefit obtained. The results of BCR also showed 6 m^3 biogas plant was more financially profitable than 8 m^3 plants. Biogas investment was more financially profitable under the assumption

Table 10 Sensitivity analysis of biogas plant investment for changes in key variables

Variables	NPV values change as key variables change			
	Plant size	**Discount rate (9%)**	**Discount rate (10%)**	**Discount rate (12%)**
Base case	6 m^3	60,767 (55,263)	56,508 (51,053)	49,088 (43,731)
	8 m^3	59,738 (54,233)	55,674 (50,219)	48,591 (43,252)
Increase in price	6 m^3	31,113 (18,462)	27,648 (16,406)	247,570 (1469)
	8 m^3	45,425 (1902)	40,365 (1795)	36,145 (1607)
Decrease in price	6 m^3	22,430 (28,946)	20,085 (32,325)	23,770 (34,257)
	8 m^3	55,525 (2531)	49,340 (2388)	44,182 (2139)
Increase in level of expenditure savings	6 m^3	49,089 (43,732)	56,509 (51,055)	60,768 (55,264)
	8 m^3	48,634 (44,152	55,743 (51,318)	59,739 (54,236)
Decrease in level of expenditure savings	6 m^3	59,667 (54,261)	55,512 (51,641)	48,189 (49,732)
	8 m^3	58,538 (55,333)	56,673 (50,719)	50,991 (44,651)

Figures in the parentheses represent NPV values without subsidy

with subsidy for both biogas plant sizes, while it was unprofitable under the assumption without subsidy in the initial year (Table 9).

The effect of the biogas subsidy on NPV was analyzed and respective trends were found. Accordingly, break-is reached during the 7th year for households purchasing firewood. For households collecting firewood and dung, however, break-even is reached during the 18th and 14th year, respectively, without subsidy. The greatest effect of subsidy is realized for households collecting firewood. Without subsidy, households collecting firewood and adopting a larger biogas plant sizes realize positive NPV value in relatively shorter years than smaller sizes.

Sensitivity analysis

The calculated benefits and costs of a project may vary depending on differing assumptions about the input data and methodology applied in the cost benefit analysis (Kalinichenko et al., 2017). The range of potential outcomes for differing inputs can be gauged using a sensitivity analysis. Sensitivity analysis results of the NPV of biogas investment were presented (Table 10). Sensitivity analysis was conducted in three scenarios: input price scenario, the level of expenditure saving scenario and discount rate scenario. The base case, which is a standard for this study, was used as reference for comparison of changes in NPV of biogas plants. For the level of expenditure saving scenario, the minimum (for decreasing), average (for base case) and maximum (for increasing) values of expenditure saving were used as input data. Based on these data, the level of expenditure saving was assumed on average 10%, decreasing and 10% increasing from the base case. The input price scenario was taken based on market price assessment of the local market, the past price (for decreasing), current (for base case) and foreseeable future price (for increasing) values. Thus, the input price scenario was assumed as 10%, decreasing and 20% increasing prices.

Based on the researchers' logical basis of market price changes in demand and supply for money, the discount rate scenario was assumed 10% for the decrease discount rate and 20% for increase discount rates from the base case (the standard for the study is 10%). Sensitivity analysis was then conducted to determine changes in cost of biogas investment as price of construction materials and maintenance cost, which could be sensitive to change. Sensitivity analysis was also conducted to determine changes to household benefit accumulation under different conditions. These conditions include level of expenditure saving firewood, kerosene and chemical fertilizer.

The level of expenditure saving may change household consumption patterns. On the other hand, as the level of saving changes the monetary benefits that would generate from biogas plant changes. For households collecting dung and for households collecting firewood, the shadow price and market price of replacing fuel increase soundly. This signals the importance of opportunity cost of labour in determining the anticipated benefits of investing in biogas plants. Thus, well-off households stand to benefit more than poorer households. Change in the benefits accruing with a larger plant size is higher for increases in shadow price of replacing fuel compared with smaller plant size. It was; however, lower when it comes to the level of expenditure and time saving. Besides, sensitivity to change is higher for households collecting firewood and dung compared to households purchasing firewood.

The NPV for the 6 m^3 plant was highly sensitive to input prices, the level of expenditure savings and discount rates than that of 8 m^3 plant across three scenarios, which could give the discounted return at the shorter

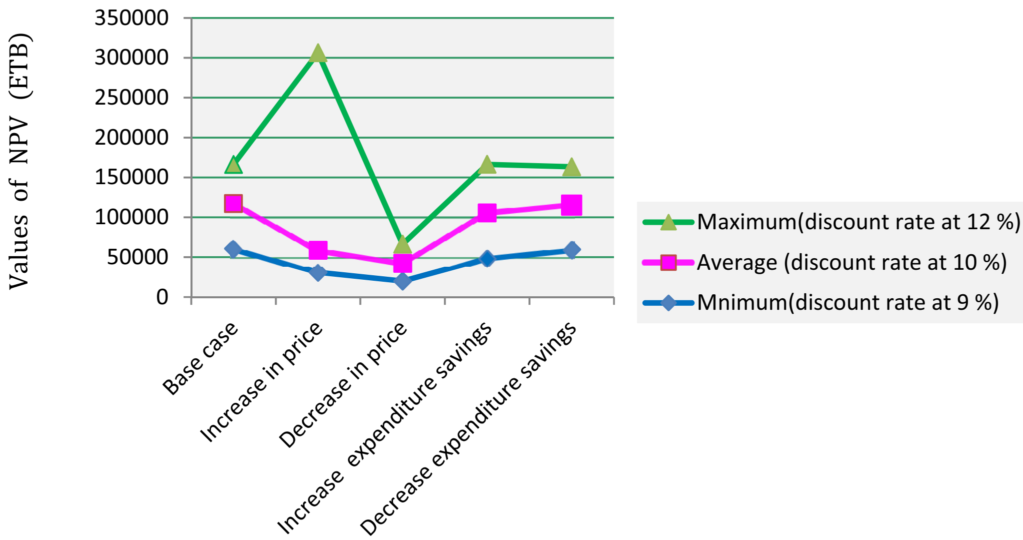

Fig. 2 Sensitivity analysis for 6 m^3 plant NPV values change as key variables change

time period (Table 10). A similar result was reported that compared to larger sizes, the NPV for smaller plant type was highly sensitive to time savings, construction costs, expenditure levels and the price of replacing fuel across household scenarios. These variables are under the household status sensitivity scenario and indicate the importance of household variables, especially for households collecting firewood and dung (Gwavuya et al., 2012). Likewise, as these key variables would be changed, the NPVs also changed, assuming the other variables remain constant such as economic life of biogas plant. The same is true; the magnitude of NPV in both plant sizes and assumptions (with and without subsidy) would change. Therefore, the best scenario NPV occurs when the level of expenditure savings increases while the input prices and discount rates decrease. The worse NPV scenario occurs when input prices and discount rate increase, and the level of expenditure savings decreases. This result is supported by Rasheed et al. (2016) that discounting is making events at different points in time that long economic life of the projects is sensitive to that of discount rates. Therefore, the choice of an appropriate discount rate is highly important to ensure future project returns. As input prices and level of expenditure change, the sensitivity of NPVs value increases (Gwavuya et al., 2012) (Fig. 2).

Benefits of biogas technology in emission reduction and improving health

The human influence on the climate comes from emissions of three greenhouse gases (GHGs) in particular carbon monoxide, methane and nitrous oxide (Boulamanti et al., 2013). The use of biogas energy enabled the biogas adopter households to be able to reduce the consumptions of various traditional biomass fuels like fuel wood, charcoal, dung cake and agricultural residue and, in turn, emissions of GHGs. The average amounts of GHG emission reductions obtained through the reduced use of dung fuel, kerosene, and fuelwood were 2.7 t, 182 kg, and 45 kg of carbon dioxide equivalent (CO_2e) per digester per annum, respectively (Mengistu et al., 2016). The main justification for the highest GHG emission reduction from the use of dung fuel is, obviously, the shift in its role from direct combustion in air-dried form to an input for the biogas digester. According to Lansche and Müller (2017) for every unit of heat energy138 conveyed to the cooking pot, the biogas system released 45% lower GHG in CO_2e than the dung combustion system. The biogas technology assisted in reducing GHG emission by about 2.3 t of CO_2e per digester annually (Mengistu et al., 2016). However, 10% of the biogas generated was assumed to be escaped to the atmosphere. The average annual emission of methane from the biogas plants would be 460 kg of CO_2e. Hence, the net annual average GHG emission reductions per unit biogas installation would be 1.9 t of CO_2e (Akter et al., 2021). The daily collection of cattle dung for feeding the digesters and toilet-connections to the digesters helps controlling emissions of GHGs like methane in the digesters (Yu et al., 2008) (Fig. 3).

The utilization of biogas technology highly reduced the problem of health through the declined use of traditional

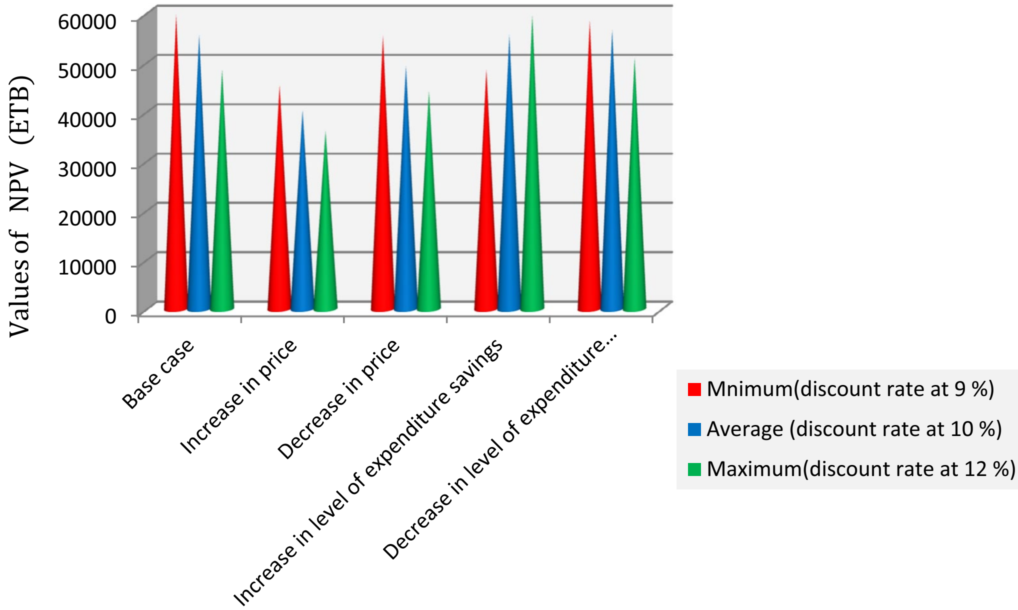

Fig. 3 Sensitivity analysis for 8 m^3 plant NPV values change as key variables change

biomass fuels. According to Mengistu et al. (2016) in Ethiopia the eye diseases, respiratory problems caused by indoor air pollution like coughing and asthma, headaches, back pain resulting from heavy load of traditional biomass fuels, injury mishap during fuel collection, and burning accidents were the health problems that were reported decreasing by 87 (67.4%), 54 (41.9%), 39 (30.2), 28 (21.7%), 11 (8.5%), and 2 (1.6%) of the respondents, respectively. 75% of the respondents in Tanzania realized the health improvements of women due to shifting from the use of fuelwood or kerosene to biogas cooking (Laramee & Davis, 2013). Besides, the use of biogas lamp is a great relief for those students who used to study at home with kerosene lamps. While studying with kerosene lamp, the lamp needs to be brought closer. When it is brought closer, eye irritation and inhaling kerosene soot are inevitable.

Application of biogas plants in the Kebeles

The use of biogas plants played a substantial role in the reduction of the amount of firewood, kerosene and chemical fertilizers consumptions of households. Specifically, the biogas energy helped adopters by providing an alternative source of energy through substituting the use of traditional fuels for cooking and lighting and kerosene for lighting while the use of bio-slurry substituted the use of chemical fertilizers. In doing so, the use of the plants increased household income, reduced deforestation, abridged women's drudgery and avoided indoor air pollution. The adopter households were satisfied with the installation of the biogas plants despite that there were constraints, including shortage of spare parts, inadequate maintenance services, lack of stove for baking local bread and high initial invest cost.

Conclusions

The study aimed at evaluating financial viability of biogas technology at household level in Aleta Wondo district, Southern Ethiopia. It specifically focuses on the fixed-dome model of biogas plant sizes of 6 m^3 and 8 m^3 and estimated their cost–benefit analysis and financial viability at household level. Although biogas technology has continued to be adopted by households through incentives, its financial viability was undisclosed to the rural households in the study area. This study elucidates these problems of uncertainty and shows as biogas investment is financially viable.

The total costs of biogas investment were ETB 13,286 and ETB 16,079 for 6 m^3 and 8 m^3 plant sizes, respectively. The respective benefits obtained from the two sizes were ETB 9,744 and ETB 10,341, showing that the costs are higher than the benefits. Likewise, the corresponding installation costs were ETB 12,775 and ETB 15,460. Proportionately, the installation cost was the leading investment cost that primarily hindered the successful dissemination of biogas technology.

Adoption of biogas technology not only substantially reduces the consumption of firewood, kerosene and chemical fertilizer, but also markedly enhances household's income by saving their purchasing expenses.

The financial analysis of both plant sizes, installed with subsidy, had higher NPV value, UPBP of less than 1 year and a BCR value of greater than one. This implies that subsidy is important to enhance biogas plant installation, particularly in larger sizes. Nevertheless, both plant sizes, installed without subsidy, had smaller NPV values and UDBP values greater than 1 year, making this scenario financially less viable. Distinctly, the 6 m^3 size is highly profitable than the 8 m^3 size. However, both plant sizes are financially viable and profitable at 10% discount rate. Moreover, sensitivity analysis showed that the profitability of biogas investment, expressed in NPV, is highly sensitive to variation in discount rates, level of expenditure savings and input prices. Households estimate the profitability of biogas plant installation primarily from monetary surplus gained from utilizing biogas energy and bio-slurry in association with the cost of the plants.

Households are often motivated by subsidy and loan, which attract the engagement of low-income households in biogas plant installation. Furthermore, household's investment in biogas plant installation is more financially viable under the assumption with subsidy than without subsidy. Therefore, for the successful dissemination of the biogas technology and further popularization, the operating subsidy scheme, being offered by the NBPE and SNV—Ethiopia, should continue at least for a certain period and until the biogas benefits are effectively familiarized among rural households.

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Author contributions

All the three authors designed the research and conducted primary data collection and analysis for the studies. In addition, the authors edited and approved the final manuscript.

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Availability data and materials

All the data are contained in the manuscript in the form of tables.

Declarations

Competing interests

The authors declare that they have no competing interests.

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