Biogas as an alternative to fuelwood for a household in Uleppi sub-county in Uganda

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Abstract: Over 93% of Uganda's population relys on wood fuel in form of either charcoal or fuelwood for cooking. Uleppi sub-county in Arua district is a typical example of such areas in Uganda where households entirely use fuelwood to meet their energy demand for cooking. The use of fuelwood is however associated with the use of inefficient stoves that accelerate deforestation thus increasing carbon dioxide (CO_2) emissions. The use of fuelwood is also associated with a smoky environment that has adverse health impacts on women and children who spend long hours in the kitchen. In addition, women and children spend long hours gathering fuelwood which significantly reduces farm productivity. This project was therefore aimed at design and construction of a biogas plant ideal for a household in Uleppi sub-county as an alternative to fuel wood. The research involved sizing of the floating drum biogas digester and gasholder, economic analysis as well as estimating CO_2 emission reduction. For a household with an average of three heads of cattle managed in a free range system, the biogas digester and gasholder were sized as 1.4 m^3 and 0.29 m^3 respectively with 0.48 m^3 of biogas produced per day. At this capacity, it was found that biogas utilization can reduce individual household consumption of wood fuel by 66.32% for a household size of five persons. The carbon emission reduction for all households was estimated at 432 tons of CO_2 per year. The benefit-cost ratio was found to be 3.26, hence worthy to invest in the biogas technology. The capital recovery period for 459 USD of the biogas plant installation with an economic life of 15 years at 23 % interest rate was found to be two years.

Keywords: biogas, carbon dioxide, emissions, fuelwood, floating drum, Uganda

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1 Introduction

Uganda is one of the countries with the least access to modern energy services. According to the Ministry of Energy and Mineral Development (2003), over 93% of Uganda's primary energy needs are covered by biomass (i.e. firewood and charcoal) whereas 6% is produced through the combustion of fossil fuels (transport and industry) and only 1% consists of electricity out of hydro-power and thermal power plants (burning oil and diesel). However, biomass which is by far the most important energy carrier is used in a highly inefficient way primarily for cooking, leading to the unsustainable utilization of Uganda's forestry resources. The ongoing pressure on the remaining resources, including forest reserves, is worsened by the ever increasing population growth currently approximately 3.5% per annum (UBOS, 2012).

Uleppi sub-county is located in Arua district, West Nile sub-region of the Republic of Uganda. According to the Arua District State of Environment report (2007) the economic activities of the people of this sub-county include cattle keeping, charcoal production and farming. According to housing and population census (2002), Uleppi has a population of 6240. Figure 1 is a map of Arua district showing location of Uleppi sub-county.

Fuel wood in the unprocessed form or as charcoal is the most widely used form of energy in Uleppi

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sub-county due to the fact that fuel wood is readily available and in most cases it is free to most households. It is also perceived to be the cheapest form of energy available to the low income households. However, the practice of charcoal and wood production has led to deforestation responsible for increased carbon emissions into the atmosphere. In addition, women and children spend long hours gathering firewood, which significantly reduces farm productivity. Besides, the use of fire wood results in smoky cooking environment that has adverse health impacts on children and women. Biogas may be a sustainable alternative to wood fuel in Uleppi sub-county since cattle keeping is one of the major economic activities for most households.

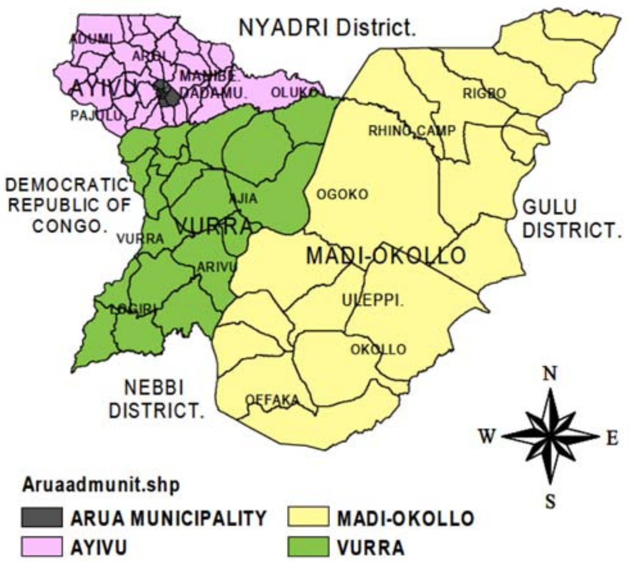

Figure 1 Map of Arua showing location of Uleppi sub-county (Arua DDP, 2002)

1.1 Properties of biogas

Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2) as its chief constituents. It also has traces of hydrogen sulfide (H_2S), oxygen (O_2), ammonia (NH_3), hydrogen (H_2) and water vapor (H_2O). Table 1 shows the composition of biogas.

Table 1 Composition of biogas (Yadava et al., 1981)

Substances	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon Dioxide	CO_2	30 - 40
Hydrogen	H_2	5 - 10
Nitrogen	N_2	1 - 2
Water vapor	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

1.2 Digestive process

Anaerobic digestion is a four-stage process that decomposes organic materials in the absence of oxygen, producing biogas as a waste product as is shown below:

Stage 1: Hydrolysis: The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials which are acted on means of enzymes to low-molecular compounds including monosaccharides, amino acids, fatty acids and water. The bacteria enzymes engaged in hydrolysis further decompose the substrate components to small water-soluble molecules, polymers turn into monomers.

Stage 2: Acidification: The monomer such as glucose which is produced in Stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules of less atoms of carbon (acids) which are in more reduced state glucose. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Stage 3: Acetogenesis: In this stage, acetogenic bacteria produce initial products (i.e. acetic acid, carbon dioxide and hydrogen) for methane formation from organic acids.

Stage 4: Methanization: The products of Stage 3 are processed by methanogenic bacteria to produce methane. The reaction that takes place in the process of methane production is called methanization and is expressed by the following Equations (Karki et al., 1984).

$$CH_3COOH(aq) \rightarrow CH_4(g) + CO_2(g) \quad (1)$$

$$2CH_3CH_2OH(aq) + CO_2(g) \rightarrow CH_4(g) + 2CH_3COOH(aq) \quad (2)$$

$$CO\,(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O \quad (3)$$

1.3 Factors influencing biogas production

There are many facilitating and inhibiting factors that play a role in biogas production process as discussed below:

pH: The optimum biogas production is achieved when the pH value of inputs mixture in the digester is between 6 and 7. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of

NH_4 increases due to digestion of nitrogen which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 and 8.2.

Temperature: The methane producing bacteria (i.e. thermophilic and mesophilic bacteria) depend on temperature. The thermophilic bacteria thrive at temperatures between 47-55℃ whereas the mesophilic bacteria operate best between 27℃ and 38℃ (Lund et al., 1966).

Loading rate: This is the amount of raw materials fed per unit volume of digester capacity per day. About 6 kg of dung per m^3 volume of digester is recommended in case of cow dung fed biogas plant. Overfeeding leads to accumulation of acids which inhibit methane production. On the other hand, under feeding can lead to low gas production.

Retention time: This is the average period within which a given quantity of input remains in the digester to be acted by the methanogens. According to Chengdu Biogas Research Institute (1989) in a cow dung plant, a retention time of 40 to 50 days is desirable. Thus, a digester should have a volume of 40 to 50 times the slurry added daily. The retention time is also dependent on the temperature; the higher the temperature, the lower the retention time (Lagrange, 1979).

Nutrients: The maintenance of optimum microbiological activity in the digester is crucial to gas generation and consequently is related to nutrient availability. Two of the most important nutrients are carbon and nitrogen and a critical factor for raw material choice is the overall C/N ratio. Adequate water is necessary for the physiological functions of the microorganisms. In case of cow dung fed digester, the typical mixing ratio is 1 water: 1 dung to provide slurry of specific density 1.089.

Stirring: When solid materials not well shredded are present in the digester, gas generation may be impeded by the formation of a scum that is comprised of these low-density solids that are enmeshed in a filamentous matrix. In time the scum hardens, disrupting the digestion process and causing stratification. Agitation can be done either mechanically with a plunger or by means of rotational spraying of fresh influent.

Toxicity: Minerals ions, heavy metals and detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect. Detergents including soap, antibiotics, organic solvents, etc., inhibit the activities of methane producing bacteria and addition of these substances in the digester should be avoided (Chengdu Biogas Research Institute, 1989).

This research was therefore aimed at design and construction of a biogas plant ideal for a household in Uleppi sub-county as an alternative to fuelwood. The research involved sizing of the floating drum biogas digester and gasholder, economic analysis as well as estimating CO_2 emission reduction. The project targeted the use of cattle dung as feedstock for the biogas digester.

2 Materials and methods

2.1 Design criterion

The design involved sizing both the biogas digester and gas holder as discussed below.

2.1.1 Sizing the biogas digester

Due to scarcity of data on the number of cattle in Uleppi sub-county, an estimate was made using data of Arua district where Uleppi sub-county is located. There are 18 sub-counties and 65,936 heads of cattle in Arua district. The number of households in Uleppi sub-county is 1,459 (Arua District State of Environment Report, 2007). The assumption was made that each of the sub-county had an average population of 1,459 households.

$$\text{Average number of cattle per household} = \frac{\text{Total number of cattle in the district}}{\text{Total households in the district}}$$

$$= \frac{65936}{1459 \times 18} = 2.5 \approx 3 \text{ (heads of cattle) household}^{-1}$$

A zero grazed local cow produces an average of 10 kg of dung per day. However, in Uleppi sub-county, cattle is kept using the free range system. It was assumed that only 50% of the dung is available for biogas production.

Input data

Dung available as a feedstock for the digester = 50%×10 = 5 kg (head of cattle)$^{-1}$

Total available biomass per household = 5×3 = 15 kg day^{-1}

Cow dung is mixed with water at a ratio of 1:1 to form slurry of specific density 1.089 (NABARD, 2007)

The substrate input for the digester was calculated according to Equation (4) as is shown below:

$$\text{Substrate input, } S_d = \text{Biomass (B)} + \text{Water (W)} \quad (4)$$

$$= 15 + 15 = 30 \text{ kg}$$

$$\text{Volume of substrate, } V_s = \frac{30}{1089} = 0.0275 \text{ m}^3$$

The volume of the digester was determined using Equation (5):

$$V_d = V_s \times RT \quad (5)$$

where, V_d is the volume of biogas digester, m^3; S_d is the substrate input, kg; RT is the retention time, days.

According to Chengdu Biogas Research Institute (1989), cow dung biogas plants require retention time of 40 to 50 days. A retention time of 50 days was used in the design.

$$V_d = 0.0275 \times 50 = 1.38 \text{ m}^3$$

The volume of the biogas digester was found to be 1.38 m^3. However, the digester should be constructed slightly above the ground to prevent runoff water from flowing into the biogas digester. Thus the volume of the digester was taken as 1.4 m^3 slightly above the 1.38 m^3 obtained from computations.

KVIC (1993) recommends a depth to diameter ratio of between 1.0 and 1.3 is suitable for all digesters. Using h:d ratio of 1.1, the Equation (6) was used to compute the diameter, d and height, h of the biogas digester.

$$V_d = \frac{\pi d^2 h}{4} \quad (6)$$

$1.4 = \dfrac{\pi \times d^2 \times 1.1d}{4}$; Diameter, d = 1.17 m; Depth; $h = 1.1 \times 1.17 = 1.29$ m

KVIC (1993) recommends that the maximum height of the inlet tank should be 1 m. The volume of the inlet tank was placed at 50% more than the daily available volume of feedstock, V_s. This capacity of the mixing tank helps to prevent spillage of slurry during mixing thus improving operational convenience to the household. The volume of the mixing tank was computed as follows:

$$\text{Volume of mixing tank} = 1.5 \times V_s = 1.5 \times 0.0275 = 0.04 \text{ m}^3$$

The most commonly used shape for mixing tanks is the cylindrical shape. Choosing arbitrarily a depth, h of 0.4 m, the diameter of the mixing tank was computed using Equation (6) above.

$0.04 = \dfrac{\pi \times d^2 \times 0.4}{4}$; Diameter, d= 0.36 m.

2.1.2 Sizing the gas holder

The size of the gas holder depends on the gas production and the consumption. The gas production capacity depends on the gas yield of a given substrate. Table 2 shows the gas yields, G_y per kilogram of feed stocks including cow dung. The gasholder capacity, V_g was computed using Equation (7) while daily gas production, G was computed using Equation (8).

$$V_g = 0.6 \times G \quad (7)$$

where, V_d is volume of the gas holder, m^3; G is daily gas production, m^3.

$$\text{Daily gas production, } G = G_y \times S_d \quad (8)$$

$G = 0.032 \times 15 = 0.48$ m^3, which is gas produced per day. Therefore, the volume of gas holder, $V_g = 0.6 \times 0.48 = 0.29$ m^3.

Table 2 Gas production potential of various types of dung (Updated Guidebook on Biogas Development, 1984)

Types of dung	Gas production per kg dung/m^3
Cattle (cows and bullocks)	0.023 - 0.040
Pig	0.040 - 0.059
Poultry (Chickens)	0.065 - 0.116
Human	0.020 - 0.028

KVIC (1993) recommends a diameter of the gasholder of 15 cm less than that of the biogas digester. This allows for movement of the gas holder up and the down without rubbing itself on the biogas digester. Thus the diameter, d_g of the gas holder was computed using the Equation (9) while the corresponding height, h_g was determined using Equation (10).

$$d_g = d - 0.15 \quad (9)$$

$$V_g = \frac{\pi d_g^2 h_g}{4} \quad (10)$$

where, d_g is the diameter of the gas holder, m; h_g is the height of the gas holder, m.

$d_g = 1.17 - 0.15 = 1.02$ m

$h_g = 0.35$ m

Figure 2 shows a dimensioned sectional view of the biogas plant while Figure 3 shows the plan view of the biogas plant while.

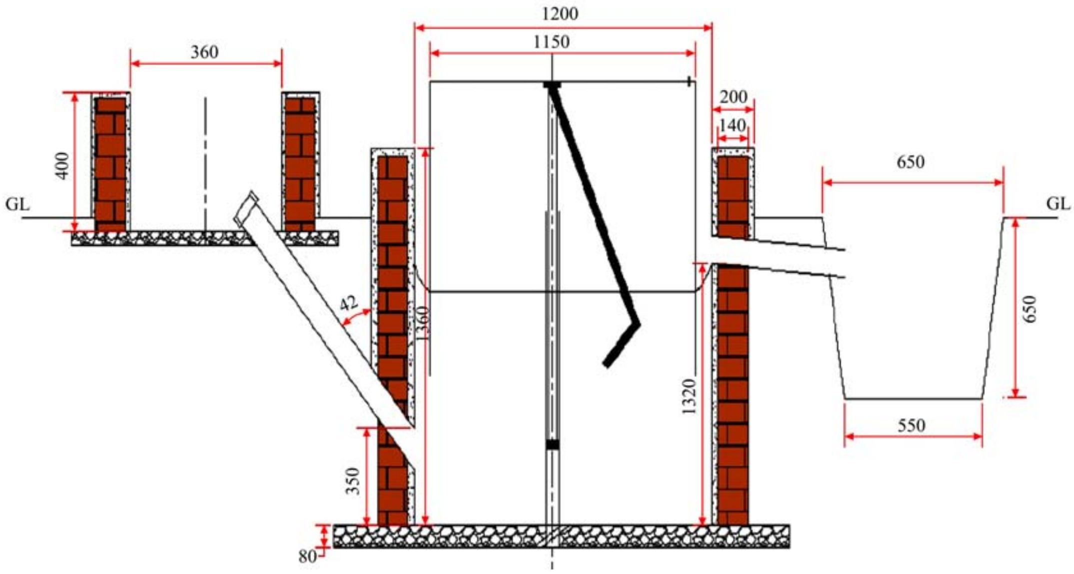

Figure 2 Sectional view of the biogas plant

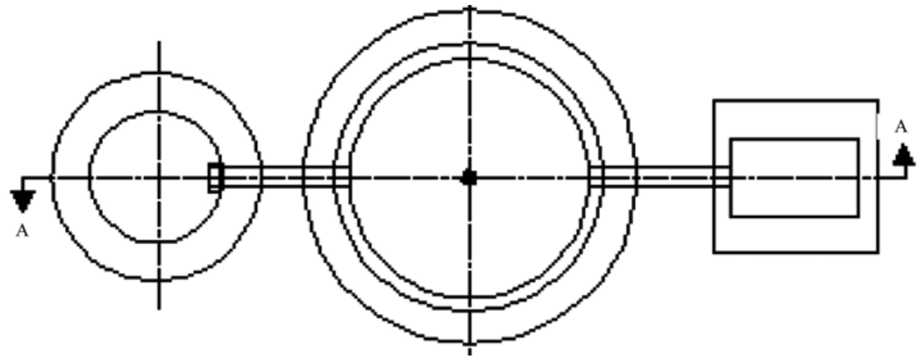

Figure 3 Plan view of the biogas plant

2.2 Estimating carbon emission saving

The amount of carbon emissions saved depends on the amount of wood fuel replaced by biogas, the net calorific value of wood fuel and the carbon emission factor of the wood fuel.

2.2.1 Determining the energy produced by the biogas plant

The energy produced by the biogas plant depends on the gas produced and the net calorific value, NCV_b of biogas. Since the average net calorific value of biogas is 20 MJ m^{-3}, the energy produced by the biogas plant was determined using Equation (11).

Daily energy production, $E = G \times NCV$ (11)

$= 0.48 \times 20 = 9.6$ MJ

$= 2.67$ kWh day^{-1}

2.2.2 Determining the amount of wood replaced by biogas

The amount of wood, M_w replaced by biogas depends on the energy produced by the biogas plant and combustion efficiencies, η_w of biogas stove and wood fuel stove used respectively. The values of the efficiencies are shown in Table 3. The amount of wood fuel offset by biogas and total amount of wood, M_y replaced yearly by targeted households was estimated as shown below.

Since the conventional biogas stove is 55 % efficient, then the useful energy is equivalent to: $0.55 \times 2.67 = 1.47$ kWh day^{-1}.

Since the three stone stove is only 8% efficient, it will require more wood to produce the same energy as that generated from biogas as is shown in Equation (12).

The total wood replaced by biogas per day was obtained from Equation (13):

$$\eta = \frac{\text{Energy output}}{\text{Energy input}} \quad (12)$$

$$\text{Energy input (kWh)} = \frac{\text{Energy output}}{\eta} = \frac{1.47}{0.08}$$

$$\approx 18.38 \text{ kWh day}^{-1}$$

$$\text{Amount of wood replaced by biogas (kg)} = \frac{\text{Energy input (J s}^{-1}) \times 3600 \text{ s} \times 1000}{\text{Calorific value (GJ ton}^{-1})} \quad (13)$$

According to Jenkins (1993), the calorific value of wood is 15 GJ ton^{-1}.

Amount of wood replaced by biogas

$$= \frac{18.38 \times 1000 \times 1000 \times 3600}{15 \times 10^9} = 4.41 (\text{kgwood}) \text{day}^{-1}$$

Total amount of wood, M_y replaced yearly by targeted households = 1459×4.41×365 = 2349.11 tons year^{-1}.

Table 3 Efficiency of stoves using different fuels (Perera et al., 2002)

Type of stove	Efficiency/%	Fuel type
Three stone stove	8.0	Fuel wood, agric-residues
Single and two pot mud stove	13.0	Fuel wood, agric-residues
Anagi stove 1 & 2	18.0	Fuel wood
Sarvodaya two pot stove	22.0	Fuel wood
CISIR'S single pot stove	24.0	Fuel wood
IDB stove	20.0	Fuel wood
NERD stove	27.0	Fuel wood
Convention biogas stove	55.0	Biogas
Ceylon charcoal stove	30.0	Charcoal

2.2.3 Determining the carbon emissions saved

The carbon emission savings obtained by implementation of the biogas project depends on the amount of wood fuel offset, net calorific value of wood fuel and the carbon emission factor of wood fuel. The carbon emission savings, *ER* were therefore computed using Equation (14).

$$\text{Carbon emission saving, } ER = M_w \times EF_w \quad (14)$$

According to DEFRA (2010), the carbon emissions factor, EF_w of wood pellets is 183.9 kg CO_2 per tonne of wood fuel.

Total emissions reduction, ER = 2349.11 × 183.9 = 432002.9 kg CO_2 per year = 432 (tons CO_2) year^{-1}.

2.3 Cost benefit analysis of the biogas plant

The cost benefit analysis was done by estimating the total benefits and the costs incurred by the household and then preparing a cash flow. The cash flow diagram was used to establish the benefit ratio and then the return period.

2.3.1 Gains from the gas produced

It was estimated that the biogas produced replaces 4.41 kg of wood fuel per day per household. The gains of the gas produced were estimated as is shown below:

Assumptions made:

Market price of wood in Uleppi sub-county is 0.2 USD per kg

Daily saving on wood fuel per household = 4.41 × 0.2 = 0.88 USD

Annual saving on woodfuel per household = 0.88 × 365 ≈ 321 USD

2.3.2 Quantification of manure from the biogas plant

NABARD (2007) reported that one tone of fresh dung produces 240 kg of manure while the NPK content of biogas slurry is 1.4%, 1% and 0.8% respectively. Given that the loading rate is 15 kg day^{-1}, the annual loading rate is 365×15 = 5475 kg year^{-1} = 5.475 ton year^{-1}. Therefore total amount of manure produced = 5.475×240 = 1.314 ton year^{-1}. Table 4 below shows the amount of NPK produced by the biogas plant annually.

Table 4 Amount of NPK available in the manure

Nutrient	Composition/%	Quantity of nutrient/kg year^{-1}
N	1.4	18.4
P	1.0	13.1
K	0.8	10.5
Total	3.2	42.0

The market price of NPK fertilizer in Uganda is 2 USD per kg. Annual savings by the household on manure alone = 2×42 = 84 USD per year.

2.3.3 Payback period of the biogas plant

The capital cost of the biogas plant is 459 USD. The details of the cost estimation of the biogas plant are indicated in the bill of quantity in Table 5.

The major operation costs were found as annual painting, and de-rusting of the gasholder. KVIC (1993) recommended that the gasholder should be replaced after five years otherwise the gasholder will become prone to leakages. The annual cost on de-rusting and painting was estimated at 23 USD. However the cost of replacing the gasholder was estimated at 183 USD. Table 6 summarizes the costs and benefits of installation and running the biogas plant.

Table 5 Cost estimate of the biogas plant

S/No.	Item	Unit	Quantity	Unit Cost (USD)	Total cost (USD)
1	Gasholder				
	Galvanized Iron sheet	m^2	3.5	32	112
	Horse pipe	m	6	4	24
	Valve, nipples and seal	Inch	1	7.6	7.6
	Ring clamp	N/A	2	1.2	2.4
	Paint	L	4	5.6	22.4
	Labor	Days	3	4.8	14.4
	Subtotal				182.8
2	Digestion tank				
	Earth work	Days	2	3.2	6.4
	Bricks		500	0.12	60
	Coarse aggregate	m^3	0.4	25	10
	Fine aggregate	m^3	4	11.2	44.8
	Cement	50 kg bags	5	13	65
	PVC pipes and plugs	m	6	2.8	16.8
	Labor	Days	4	7.2	28.8
	Subtotal				231.8
3	Biogas stove		1	44	44
	Grand total				459

Table 6 Costs and the gains of the biogas plant

Expenditure	Amount/USD
Capital	459
Annual cost of painting and de-rusting	23
Gasholder replacement after every 5 years	183
Annual gains	
Wood saving	321
Manure	84
Total annual gains	405

Figure 4 shows the net-cash flow for the costs and benefits associated with installation, operation and maintenance of the biogas plant over its economic life of 15 years provided maintenance and repair are carried out regularly. An assumption was made that the household acquires a loan of 459 USD from a bank that charges an interest of 23 % per annum.

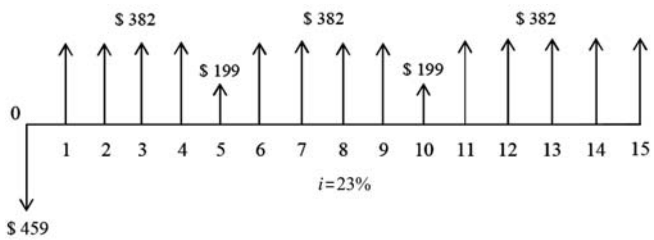

Figure 4 Net cash flow diagram of running the biogas plant

The net present value was computed using Equation (15).

$$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] \tag{15}$$

For benefits; the net present value was computed as:

$$P_{1\text{-}4} = 382\left[\frac{(1.23)^4 - 1}{0.23*(1.23)^4}\right] = \$\ 935.24$$

$$P_5 = \frac{199}{1.23^5} = \$\ 70.69$$

$$P_{6\text{-}9} = 382\left[\frac{(1.23)^4 - 1}{0.23*(1.23)^4}\right] = \$\ 935.24$$

$$P'_{6-9} = \frac{935.24}{1.23^5} = \$\ 332.2$$

$$P_5 = \frac{199}{1.23^{10}} = \$\ 25.11$$

$$P_{11\text{-}15} = 382\left[\frac{(1.23)^5 - 1}{0.23*(1.23)^5}\right] = \$\ 1070.93$$

$$P'_{11-15} = \frac{1070.93}{1.23^{10}} = \$135.12$$

Total net present worth of benefits = 135.12+25.11+ 332.2+70.69+935.24 = $ 1498.36

The benefit-cost ratio was determined using Equation (16).

$$\text{Benefit-cost ratio} = \frac{\text{Present worth of benefits}}{\text{Present worth of costs}} = \frac{1498.36}{459} \approx 3.26 \tag{16}$$

Since the benefit-cost ratio is greater than one, then adopting biogas technology is a profitable venture hence worthy to invest in.

The payback period of the biogas plant was obtained by finding the number of years for which the net present benefits of the project were equal to the net present costs of the project.

The net benefit per year is given by:

$$\frac{Pi\ (1+i)^N}{(1+i)^N - 1} = A$$

$$\frac{1498.36 \times 0.23\ \times (1.23)^{15}}{(1.23)^{15} - 1} = A$$

$$A = \$\ 360.79$$

$$360.79 \times \left[\frac{(1.23^N - 1)}{0.23 \times (1.23^N)}\right] = 459$$

$1.23^N = 1.41$

$N = 1.7$ years

The cost benefit analysis of the biogas plant shows that the capital investment of 459 USD can be recovered in about two years. There are also incidental benefits of hygienic improvement and carbon emissions saving which have not been reflected in the economic analysis.

3 Results and discussion

Table 7 shows a summary of results obtained from sizing of the digester and the expected outputs resulting from operation of the biogas digester. The expected outputs include daily gas production, daily energy production, fuelwood offset and annual carbon emission saving.

Table 7 Results obtained from sizing of the digester and the expected outputs resulting from operation of the biogas digester

Quantity	Unit	Result
Volume of digester	m^3	1.4
Volume of gas holder	m^3	0.29
Daily Gas produced	m^3 day^{-1}	0.48
Energy produced	kWh day^{-1}	2.67
Wood fuel offset	kg day^{-1}	4.41
Annual Carbon emission saving	tons year^{-1}	432

3.1 Biogas plant size

The major aspects of the size of the biogas plant are the size of the digester and the gas holder. The substrate available and the gas production per day were assessed and the appropriate digester and gasholder size for Uleppi sub-county were found to be 1.4 m^3 and 0.29 m^3 respectively. The daily gas production was found to be 0.48 m^3 day^{-1}. At this capacity, the gasholder provides enough storage for the biogas without any wastage. The biogas digester can hold the slurry for 50 days which is sufficient enough to exhaust the biogas content of the slurry before it flows in to the effluent storage tank where it is kept as manure.

3.2 Daily gas and energy production

The gas production rate of the biogas plant was estimated at 0.48 m^3 day^{-1}. The biogas produced can provide useful energy up to 1.47 kWh day^{-1} using a conventional stove with 55% energy efficiency. The biogas is therefore able to replace 4.41 kg of wood per day per household which previously used the traditional three stone stove of 8% efficiency. Therefore for a household with an average population of five persons and average per capita consumption of 1.33 (kg wood) day^{-1} (UIA, 2007), the total consumption per household per day would be 6.65 kg firewood. The biogas potential of per household from cattle dung is therefore able to meet up to 66.32% of the household energy.

3.3 Carbon emissions reduced

The researchers found out that the implementation of biogas projects in Uleppi sub-county results in annual carbon emission savings of 432 tons. The carbon emissions saving from biogas projects vary depending on the fuel replaced by biogas and the efficiency of the stoves used.

4 Conclusions

If the targeted households in Uleppi sub-county adopted the biogas production technology, numerous benefits will be achieved including income saving, environmental benefits such as carbon emissions reduction, health benefits, and increased farm productivity among others. The biogas technology is a profitable venture that would improve the livelihoods of the people in the area if adopted.

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