The economics of a biogas digestor

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SUMMARY

THE ECONOMIC *feasibility of a plastic biogas digestor was investigated by using a net present value (NPV) model. A sensitivity analysis determined the effects of various prices for inputs and outputs. The opportunity cost of the alternative fuels dried dung and firewood was found to be the most crucial issue for the investment feasibility of the digestor. Even at high prices for dung fuel, rural households in Ethiopia will find the digestor an attractive investment, provided that they have access to water at no cost, and family labour is available to operate the digestor at no opportunity cost. Technical and economic aspects of the system are also discussed.*

Introduction

Fuel is in very short supply in Ethiopia and throughout most of Africa. Where conditions still permit, wood is commonly used as fuel, but in many rural and urban areas, dried cow dung is a major source of fuel for cooking.

Two main problems are often cited in connection with dried dung: its use for fuel precludes its use as fertilizer, and it is often burned in open fires at very low efficiency[1]. When dung is processed into biogas and the output slurry is recovered for use as fertilizer, both problems are addressed.

[1] Wood burns at 5–8% efficiency and cow dung at 60% of that of wood (UNESCO, 1982), which implies an open-fire efficiency of only 3–5% for dung.

The energy in dung may be converted to methane at approximately 34% efficiency, which may be utilised in cooking at up to 60% efficiency. Thus by converting the energy in dung to methane, the potential energetic efficiency of dung increases from perhaps 3–5% to 20% (0.60 × 0.34).

When cow dung is burned directly in an improved stove, its energetic efficiency increases to 11% (UNESCO, 1982), but when it is first processed in a biogas digestor, both more usable energy and plant nutrients can be obtained. The nutrient content (mainly N and P) of the remaining slurry is essentially the same as in the unprocessed dung.

ILCA has developed a simple, plastic biogas digestor which processes organic matter, mostly cattle dung, into gas usable for cooking, lighting and heating. Prototypes of this digestor are currently being used by a few households in Addis Ababa, Ethiopia, and in Debre Zeit (some 50 km south of Addis Ababa), mostly to produce gas for cooking.

In a memorandum to the Director General of ILCA it was reported that the biogas digestor is both technically and economically feasible for use in Ethiopian households. A development programme was proposed comprising (a) digestor testing at different sites in Addis Ababa and at selected peasant association villages, prior to commercialisation, and (b) back-up research, mainly in the Debre Zeit area, to increase the efficient use of the digestor.

The initial economic assessment of the digestor failed to consider adequately the opportunity costs of inputs (dung, water and labour), the costs of traditional alternative sources of fuel, and the benefits of using output slurry as fertilizer. Thus its economic feasibility remained unclear.

This paper presents a more thorough economic analysis, so that the priority of the digestor for further development can be assessed, but no attempt was made to comprehensively analyse social costs and benefits. A financial analysis based on net present value (NPV) was applied to assess the feasibility of investing in a biogas digestor at Debre Zeit. Sensitivity analysis was applied to determine the effects of a wide range of prices for input dung, water and labour, and output methane and slurry.

DESCRIPTION OF THE BIOGAS DIGESTOR

Components

The biogas digestor has four major components (Figure 1):

- A cylindrical plastic bag about 7m long and 1m in diameter. The bag consists of three layers of thick plastic sheets, each of which can be removed if damaged, while allowing the remaining sheet(s) to continue functioning.
- Short inlet and outlet pipes of hard plastic, about 4 cm in diameter.
- A 15–30m long gas line (usually a plastic garden hose) with a diameter of 1.25 cm. Alternatively, a heavy PVC pipe or metal tubing may be used to channel the gas.
- A cooking burner made of bricks, cement, crushed stones, clay or mud. The gas line is fitted with a valve to control gas flow.

Component costs

Table 1 shows the costs of the digestor components, estimated on the basis of 1986 prices in Addis Ababa. The total estimated cost of the biogas digestor is EB 87 to 108 (US$ 1 = EB 2.07). This range includes the estimate of others, who maintain that the total cost does not exceed EB 100. For convenience, we shall use this maximum in the analysis.

Table 1. *Capital cost estimates of a plastic biogas digestor, Addis Ababa, Ethiopia, 1986.*

Item	Quantity	Total cost (EB)[1]	Qualitative remarks
Drum/barrel	1	25	This is the approximate cost in Addis Ababa. Other, less costly containers could also be used.
Plastic sheets	3 layers (7 × 3m)	24–32	The current price of plastic (length 4.6m, width 1m) is EB 5.20 kg^{-1}, but plastic is scarce in Addis Ababa and can be damaged by rain/wind or mishandling. Compatibility and cost aspects are important under

			rural conditions.
Inlet/outlet pipes	2	2	Hard plastic materials are easily available in urban areas; in rural areas, bamboo could be used.
Plastic hose	1 (10–15m)	25–38	Currently not available in Addis Ababa, but less costly (about EB 2.50m^{-1}) than metal tubing.
Valve for gas control	1	5	Own estimate; probably more expensive.
Cooking burner	1	5	Own estimate; probably less expensive, depending on cost of materials used and available design skills.
Thatched roof	1	1	Insignificant cost, especially in rural areas where straw is relatively abundant.
Total		87–108	

[1] EB 2.07 = US$ 1.00.

Operation

Prior to loading, equal proportions of dung and water are mixed in a drum. Materials should be kept watery, because dung with too little water slows down gas production and harms micro-organisms. The design output of 1m^3 gas day^{-1} requires a daily load of 16 kg fresh dung mixed with 16 kg water. The output is expected to provide 6 hours of cooking time to a single burner.

After the slurry mixture has been fed into the digestor, anaerobic digestion by methane bacteria and other microbes takes place over 2–4 weeks depending on prevailing temperature. When the fermentation process is complete, the bag contains gases accumulated in the upper one third, and nutrient-rich sludge in the lower two thirds (Figure 1).

Inputs

The basic inputs required to operate the digestor are dung, water and labour. The estimated requirements for the Debre Zeit installation are summarised in Table 2.

Table 2. *Estimated inputs of dung, water and labour required to produce 1 m^3 of methane gas per day, Debre Zeit, Ethiopia, 1986.*

Input	Daily requirement	Annual requirement
Dung (kg)		
• Fresh	16	5840
• Dry equivalent	6.48	2365
Water (litres)	16	5840
Labour (hours)		
Water collection	0.5	182
Slurry removal to field		
• manually	0.85	311
• manually and with donkey	0.28	103
Slurry distribution	0.25	91
Total labour		
• in hours	1.03–1.60	376–584
• in days	–	47–73

Experiments at ILCA's Debre Zeit research station showed that 45 kg of dung loaded daily into a biogas plant produced gas at the rate of 2.83m^3 day^{-1}, which corresponds to approximately 16 kg dung m^{-3} gas (Ephraim Bekele, ILCA, Addis Ababa, Ethiopia, unpublished data). This is corroborated by other studies which estimated that at 35°C, 15 kg of dung is needed to produce 1m^3 of gas (van Buren, 1974; French, 1979; UNESCO, 1981, 1982).

At 16 kg day^{-1}, the annual dung requirement of the proposed digestor is 5840 kg. Since equal parts of dung and water are necessary to mix the input slurry, the digestor's water requirements will be 16 litres daily or 5840 litres annually.

Variations in labour requirements would depend mainly on the accessibility of water and the distance of fields from the digestor. Gryseels and Goe (1984) estimated that the average Debre Zeit household already spends 91 hours (h) per month fetching water. The labour needed to collect water, prepare input slurry and distribute the output slurry on fields is estimated at 1.0–1.6 h day^{-1} or 47–73 working days $year^{-1}$. For the purposes of this analysis only the higher annual figure is used.

Outputs

Biogas and slurry are the two outputs of the system considered. As with inputs, their quantification poses some difficulties, due mainly to differences associated with feedstock quality, temperature, digestor operating parameters and the substitution rates used.

Biogas

According to FAO (1983), biogas usually contains 54–70% methane (averaging 60%), 27–45% carbon dioxide (averaging 36%) and small amounts of hydrogen, nitrogen, oxygen, carbon monoxide and hydrogen sulphide (total average 4%). Carbon dioxide and hydrogen sulphide can be removed to improve combustion efficiency, but this has not been done in this study.

The design output of methane gas from the biogas digestor considered here is $1m^3$ day^{-1}. In order to compute its value in terms of the value of traditional fuels saved by utilising biogas, it is necessary to estimate the amount of dried dung cakes or firewood needed to produce an equivalent amount of energy. The calorific values of different fuels are summarised in Table 3.

Table 3. *Calorimeter measurements of the energy values of biogas, firewood and dung cake.*

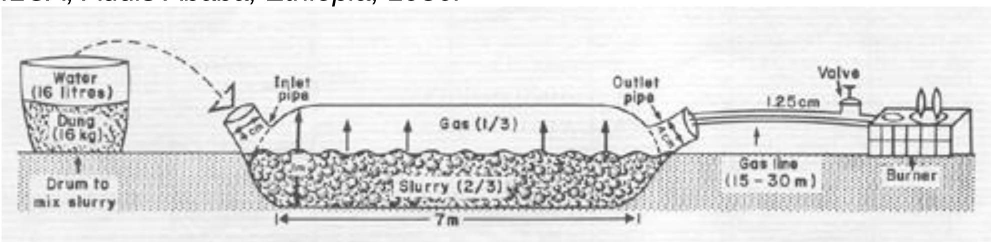
Fuel	Calorific values[1]	
	Megajoules[2] (MJ)	Kilocalories (Kcal)
Biogas (m^3)	20.0	4700
Firewood (kg)	20.0	4700
Dung cake (kg)	8.8	2100

[1] Note that the calorific values of fuels measured in a calorimeter are always higher than those under user conditions. This is due to losses caused by imperfect combustion and heat carried away in air, ashes, smoke, clinkers etc.
[2] The joule is the accepted SI unit (see Authors' style guide, p. 27) to measure energy (1 Megajoule = 10^6 joules). The equivalent in kilocalories may be more familiar and is shown for comparison.
Source: UNESCO (1982).

The substitution rates used in this study assume that $1m^3$ of biogas substitutes for 3.47 kg of firewood or 12.3 kg of dry dung fuel (UNESCO, 1982; van Buren, 1974). Assuming 5% efficiency for open-fire heating with dried dung, and using the calorific values in Table 3, 12.3 kg of dung provides 5.4 MJ (8.8 × 0.05 × 12.3) of energy. One cubic metre of gas contains 20 MJ. If $1m^3$ of gas substitutes for 12.3 kg dry dung, the gas must burn at 27% efficiency (5.4/20). This is a very conservative estimate, since methane may burn at up to 60% efficiency[2] in an improved burner (UNESCO, 1982). Investment in a more efficient gas burner may therefore prove very attractive.

[2] This figure could be obtained by assuming an 11% efficiency for dung burned in an improved stove.

Figure 1. *Components of a plastic biogas digestor producing methane at the rate of 1 m^3 day^{-1}, ILCA, Addis Ababa, Ethiopia, 1986.*



Slurry

In general, about 80% of the total solids put in a digestor can be expected to come out, and processing does not change the form or quantity of the nutrients. Increasing evidence suggests, however, that slurry is much more effective than dung when applied as fertilizer: French (1979) quoting Subramanian (1978) maintains that it is 13% more effective than dung, and van Buren (1974) reported that the ammonia content of organic fertilizer fermented for 30 days in a pit in China increased by 19.3% and its useful phosphatic content by 31.8%.

During digestion, about 20% of the total 32 kg of slurry is volatilised (UNESCO, 1982). Thus the net weight of slurry removed daily from the digestor is 25.6 kg, or 9344 kg annually. Assuming that the slurry coming out of the digestor has the same quantity of nutrients as the dung originally put in, then, in terms of fertilizer value, the annual slurry output of 9344 kg is equivalent to 5840 kg of fresh dung (which in turn is equivalent to 2365 kg of dried dung cakes) fed into the digestor annually.

Debre Zeit cow manure contains approximately 1.5% N and 1.3% P per unit dry weight (Newcombe, 1983). Thus the annual output of slurry equivalent to 2365 kg of dry dung converts to 34.5 kg of N and 30.7 kg of P. Theoretically, this constitutes a substantial fertilizer potential. However, since the slurry must be applied to cultivated fields immediately after disposal (to avoid accumulation of ammonia and toxic compounds), and considering that there are practical constraints (e.g. labour, cultural attitudes etc.) to its use, it is doubtful that the full benefits of slurry use would accrue to individual farmers.

METHODOLOGY AND VALUATION ISSUES

Financial analysis

To estimate the investment feasibility of the project, it is assumed that the financial benefits of the digestor are the value of dung and/or firewood replaced by biogas to satisfy household fuel needs. The benefits of the slurry coming out of the digestor are the value of equal amounts of N and P from a commercial fertilizer. The capital costs of the installation have been assumed to be EB 100. The input costs will be specified later.

A discount rate of 10% has been applied throughout the analysis. According to IMF (1982), interest rates charged by the Agricultural and Industrial Development Bank (AIDB) of Ethiopia on loans to farmers range from 9% (for working capital and long-term loans for fixed investment) to 10.5% (for fertilizer loans). Farmers' associations obtain fertilizer loans at 10.5% and lend to their members at 12%. Since the project's life has been limited to 2 years, however, it was not deemed necessary to look for a most precise discount rate.

The net present value (NPV) model is specified by the following equation (all calculations are in EB year^{-1}):

$$NPV = \sum \frac{TB_t - TC_t}{(1+r)^t} = \sum \frac{NB_t}{(1+r)^t}$$

where:

TB = the total annual benefits (biogas, slurry) expected from the digestor, and

TC = total costs (capital and operating costs, including costs of dung, water and labour). TB and TC are discounted to the initial year of investment (t = 1) at the selected 10% discount rate (r) over the project's lifetime of 2 years.

NB = net financial benefits of the digestor.

A zero NPV indicates that the investment will yield returns equal to the discount rate, and it is therefore an attractive investment. An NPV greater than zero indicates that the investment will yield returns in excess of the discount rate and is likewise attractive. A negative NPV indicates that the investment is unattractive.

Valuation of inputs

If inputs are utilised in the next best or most likely alternative way, or if they are readily marketable, the usual cost estimate procedure is to estimate their value by market price. This is called the opportunity cost of an input. The alternative values used in the analysis for inputs and outputs are summarised in Table 4.

Table 4. *Summary of alternative values of inputs and outputs used in the analysis.*

	Value alternative	
	High	Low
Inputs		
Dung[a] (EB[b] kg^{-1})	0.20	0.05
Water (EB per 10 litres)	0.025	0.00
Labour (EB day^{-1})	1.50	0.00
Outputs		
Biogas (EB kg^{-1})	–[c]	–[d]
Slurry (EB kg^{-1})	50.63	25.32

a. Assumes that the value of the dung is equivalent either to the value of sun-dried dung with a moisture content of about 20% (high) or to the value of an equivalent amount of fertilizer (low).
b. EB = Ethiopian birr; EB 2.07 = US$ 1.
c. Assumes that biogas replaces dung at EB 0.20 kg^{-1} or wood at EB 0.25 kg^{-1}.
d. Assumes that biogas replaces dung at EB 50.63 t^{-1} or wood at EB 0.13 kg^{-1}.

Dung. The opportunity cost of dung was estimated in terms of:

- dung's value as fertilizer determined by the cost of an equivalent amount of commercial fertilizer, or
- the market value of dung cakes, if dung is sold.

N and P contents of diammonium phosphate (DAP) roughly approximated the proportions of these nutrients in dried cow dung. Thus 1 t of DAP is roughly equivalent to 16 t of dry manure. The 1986 price[3] of DAP was EB 810 t^{-1}; thus each tonne of dry cow dung is worth EB 50.63 in terms of the plant nutrients it contains (or EB 20.50 t^{-1} of fresh dung).

[3] The price of fertilizer was determined from a receipt voucher issued to ILCA's Purchasing Unit.

The price of dried dung cake observed at the Debre Zeit market ranged from EB 3.50 to 6.00 per bundle, averaging EB 0.20 kg^{-1} of dried dung (or EB 0.08 kg^{-1} of fresh dung).

Water. This was valued either at the price charged by the Water and Sewerage Authority in Debre Zeit, i.e. EB 0.025 per 10 litres (I. Whalen, ILCA, Addis Ababa, Ethiopia, unpublished data), or at zero.

Labour. The labour used to collect water or haul and spread slurry was valued at:

- half the rural wage rate of EB 1.50 day^{-1}, i.e. the opportunity cost at which farmers can be assumed to value family labour, or
- zero, assuming that family labour has no opportunity cost.

Valuation of outputs

Biogas. The biogas produced by the digestor was valued at:

- the market value of wood or dung which it replaces, or
- at a lower value, in this case half the cost of wood replaced.

The observed price of wood in Debre Zeit was between EB 4.00 and 7.00 per bundle weighing 15–25 kg. It was estimated that firewood averages EB 5.00 per 20- kg bundle or EB 0.25 kg^{-1}. The lower value used in the sensitivity analysis is the value of wood displaced by gas at EB 0.13 kg^{-1}

Slurry. Output slurry was valued at:

- the official price of DAP containing an equivalent amount of plant nutrients, or
- half that price.

Sensitivity analysis

Prices have an important influence on relative returns to investment proposals and, consequently, on the success or failure of any investment project. Within the context of a biogas project, the most important uncertainties relate to the estimated input/output values and to the life span of the digestor. The feasibility of the investment should therefore be examined under a range of plausible price combinations for the various inputs and outputs.

A high and a low price were established for each of the three inputs and two outputs (Table 4). The potential number of combinations is 25 × 2 = 64: each of the five inputs and outputs could be evaluated at two price levels, which is calculated twice, once assuming biogas is valued by the value of the dung it replaces and again by the value of the replaced firewood.

Of the potential 64 combinations, only 24 are plausible. For example, combinations of a low price for dung as an input with a high price for biogas substituting for dung, or vice versa, are inconsistent, and were therefore not calculated. Similarly, since slurry can only be valued as fertilizer and biogas only as fuel, solutions based on valuing slurry as fuel and biogas as fertilizer have been discarded.

RESULTS

Where dung is highly valued as fuel and is burned or sold, it is unlikely that it will be displaced by biogas, at least not in the short term[4]. In those situations where dung could be used as an input to the digestor, the costs of producing biogas must be compared with those of using firewood (if the latter is available).

> [4] In many parts of Ethiopia, but especially in the high lands, the use of dung as fuel is associated with increasingly scarce firewood, which has become an expensive fuel.

The 24 selected combinations and the resultant NPVs are shown in Table 5. The solutions are numbered in order of the NPVs from highest to lowest. Of the 24 combinations, 21 yield positive NPVs, some of which are very large. These occur when biogas substitutes for dung rather than for wood which is underpriced relative to dung.

Table 5. *Combinations of assumptions about input and output values and resulting net present values when biogas replaces dung or wood, Debre Zeit, Ethiopia, 1986.*

Solution	Biogas replaces	Value of inputs			Value of outputs		NPV[1](EB[2])
		Dung	Water	Labour	Biogas	Slurry	
1	Dung	high	low	low	high	high	855
2		high	high	low	high	high	829
3		high	low	low	high	low	751

4		high	high	low	high	low	725
5		high	low	high	high	high	664
6		high	high	high	high	high	639
7		high	low	high	high	low	560
8		high	high	high	high	low	535
8_a[3]	dung	zero	high	high	zero	low	–202
9	Wood	low	low	low	high	high	459
10		low	high	low	high	high	433
11		low	low	low	high	low	355
12		low	high	low	high	low	329
13		low	low	high	high	high	269
14		low	high	high	high	high	243
15		low	low	low	low	high	184
16		low	high	low	low	high	169
17		low	low	high	high	low	165
18		low	high	high	high	low	140
19		low	low	low	low	low	80
20		low	high	low	low	low	65
21		low	low	high	low	high	5
22		low	high	high	low	high	–20
23		low	low	high	low	low	–99
24		low	high	high	low	low	–124

[1] NPV = net present value.
[2] EB 2.07 = US$ 1.
[3] Shows that the investment feasibility of the biogas digestor depends primarily on the opportunity cost of the alternative fuel: if that cost is zero, the NPV is negative.

Wood not only contains more energy per kg, but also burns with greater efficiency: with 20 MJ kg^{-1} and burning at 8% efficiency in an open fire, wood nets 1.6 MJ, while dung with 8.8 MJ kg^{-1} and burning at 5% efficiency nets 0.44 MJ. The substitution rate in burning is 3.58 kg dung kg^{-1} wood, while the substitution rate in cost terms is 25/20 = 1.25 kg dung kg^{-1} wood. At these substitution rates, dung appears to be three times as expensive as wood to produce the same net amount of energy. In practice, however, wood may not be completely dry and may therefore burn with much lower efficiency than was assumed in the calculations.

The highest expected NPV is EB 855 (Table 5). This attractive investment is obtained when the values of outputs are high and the values of input water and labour are low. Of course, if biogas substitutes for dung fuel and its value is very high, the price of dung as an input cannot be low, and vice versa; no solutions are therefore shown for such combinations.

Faced with high prices for dung fuel, Debre Zeit households can use or sell output slurry at the equivalent value of commercial fertilizer, provided that they have access to water at no cost, and family labour is available to operate the biogas digestor at no opportunity cost. For such households, the biogas digestor will prove a very attractive investment indeed (Table 5, solution 1, NPV = EB 855).

In fact, when biogas substitutes for dung with a high opportunity cost, the households can afford to take a low value for slurry, pay a high price for water and remunerate family labour, and they will still find the biogas digestor a very attractive investment. This is the situation represented by solution 8 with an NPV of EB 535.

Thus, in this problem formulation, the most important issue in determining the investment feasibility of the biogas digestor is the opportunity cost of alternative fuels. Although the use of slurry at a relatively high value adds to the attractiveness of the investment, the value of slurry *per se* is not crucial to the investment feasibility of the project. As the price of dung increases, the attractiveness of the biogas digestor will increase, or vice versa (see solution 8a which has been included for illustrative purposes: when the price of dung is set at zero, the attractiveness of the digestor falls dramatically and the NPV becomes –202).

Only three of the plausible situations in Debre Zeit indicate negative NPVs. The lowest, at –124, combines low output values with high water and labour costs. The other two solutions with negative NPVs show high labour costs with a high or a low value for slurry output.

The NPV calculations are set up on a computer spreadsheet and can be quickly executed for any set of technical or economic circumstances. The investment feasibility of a biogas digestor for any particular household can be calculated using the NPV investment criterion. Both the circumstances and the technical and economic aspects of operating the digestor vary greatly among the Debre Zeit households, but this analysis suggests that the investment would be attractive from the NPV perspective for many of them.

DISCUSSION

The analysis indicates that more efforts are warranted to promote the biogas digestor in Ethiopia. At the same time there remains much scope for analysis.

The major risk factors may be the life span of the digestor and availability of maintenance services. This analysis assumes a 2-year life for the project, but one of the prototypes tested failed in less than 1 year, while other installations may last longer than 2 years. In any case, more information about the expected life of biogas digestors is needed, and standard errors must be calculated. The need for a maintenance service or a training programme to teach owners how to maintain biogas digestors should be determined (no maintenance costs were assumed in the analysis).

Three important technical assumptions were made with respect to gas production and use, and the efficient use of inputs and their conversion. First, the average daily output of methane was assumed to be $1m^3$ day^{-1}, but this could vary considerably with daily ambient temperature fluctuations.

Second, the analysis assumed that all gas produced would be used, and that it would have the same value as the dry dung or wood displaced in cooking. It is unlikely that all the gas would be utilised every day. Full use could imply that less than peak outputs would be shortfalls requiring some alternative supplemental fuel as a backup. Alternatively, it could also imply that a biogas supply exceeding the minimum requirements for cooking was utilised for heating or lighting, both of which may represent lower-valued outputs.

Although the estimate for gas efficiency is very conservative, the second implication suggests that gas output is overvalued in the analysis. This would be more troublesome had not the NPVs been so high: most results suggest that the biogas digestor under analysis is more than marginally feasible. In fact, the investment remained feasible even with only half the biogas output utilised, which is equivalent to full utilisation at half the price.

Third, standard or adequate levels of inputs and temperature could not be accurately determined because conditions vary from one area to another. In addition, there are as yet no definite experimental results on the quantity and/or quality of inputs required to ensure optimum gas/slurry production in different environments.

Several technical aspects need further analysis:

- What is the variation in methane production in relation to temperature?
- What is the conversion efficiency of the dung/water input mixture to gas/slurry output?
- To what extent do shortfalls and surpluses occur throughout the year in a typical household operating a $1m^3$ biogas digestor?
- How can the full output be efficiently utilised throughout the year?

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