BIOGAS FOR BETTER LIFE: AN AFRICAN INITIATIVE

A COST-BENEFIT ANALYSIS OF NATIONAL AND REGIONAL INTEGRATED BIOGAS AND SANITATION PROGRAMS IN SUB-SAHARAN AFRICA

DRAFT FINAL REPORT

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Putting Ideas to Work

Executive Summary

Winrock International conducted a financial and economic cost-benefit analysis of an integrated household-level biogas, latrine, and hygiene program in Sub-Saharan Africa to help inform investment decisions related to the *Biogas for Better Life* initiative. An understanding of financial and economic returns are key ingredients in the decision-making process and the development of a successful program. Financial analysis of costs and benefits provides insight into consumer willingness to invest in combined biogas and sanitation technologies by capturing potential net returns to the household. Economic analysis of cost and benefits at the programmatic level provides donors, policy makers, and sector experts with the information needed to compare alternative development investments. The analysis was conducted for the Sub-Saharan Africa initiative as a whole as well as Uganda, Rwanda, and Ethiopia where national programs are being considered. The analysis relies on data provided by teams conducting country-level feasibility studies, other secondary sources, and limited primary data collection. For the sub-Saharan African Program, the financial internal rate of return (FIRR) for the base case scenario was 7.5% and the economic internal rate of return (EIRR) 178%.

Description of the program. The program evaluated in this study is an integrated household biogas, latrine, and hygiene program. The program involves establishing and supporting small businesses that sell subsidized biogas plants to poor African households. Households are also given the option of purchasing an unsubsidized latrine to connect to the biogas plant, which feeds human waste directly into the plant. All households are provided with hygiene education. Biogas plants use animal and human waste to produce a colorless clean gas similar to that of liquefied petroleum gas (LPG), allowing for virtually smoke-free combustion. In Sub-Saharan Africa, it is assumed that biogas will be used for both cooking and lighting, given the low level of rural electrification. The estimated number of households that will be reached through each of the country programs and the Sub-Saharan initiative as a whole are as follows: Uganda (20,000 households), Rwanda (15,000 households), Ethiopia (10,000 households), and Sub-Saharan Africa (more than 2 million households).

From the household perspective, households face costs associated with installing and operating a subsidized biogas plant. Plant costs, provided by the teams conducting the feasibilities studies, ranged from US$747-US$859 per plant. As per the feasibility studies, the biogas plant subsidy is assumed to be about 30% of the cost of the plant and ranges US$186-$US300. Households who choose to attach a latrine also incur the capital cost of the latrine. The cost of a pour-flush latrine ranges from US$200-US$284 per toilet, which seems very high but this was the information provided by country teams conducting field studies. For the purposes of the base case analysis, 50% to 75% of households are assumed to install a latrine. This assumption, along with others, is tested in the sensitivity analysis. In addition, although all households receive hygiene education, it is assumed that 60% adopt improved hygiene practices. These households will also face small incremental costs associated with purchases of hygiene-related materials, such as soap. As a result of these investments, households reap a range of financial benefits, including a reduction in fuel and lighting expenditures, increased time available for income-generating activities, and reduced health-related expenditures. All of these costs and benefits are includes in the financial analysis.

From the societal perspective, the costs of an integrated biogas, latrine, and hygiene program include all the capital and recurrent costs faced by households plus the costs of operating the program. Program-level costs include costs associated with administering the program, biogas plant subsidies, and technical assistance. The societal benefits of integrated biogas, latrine, and hygiene program include all of the financial benefits accrued by households plus a host of additional benefits. These benefits include the value of time savings associated with fuelwood collection, cooking, access to a latrine, a range of health-related benefits, and environmental benefits due to reduction in greenhouse gas emissions and deforestation. All of these costs and benefits are included in the economic analysis.

Results. A summary of the results for the base case scenario are presented below. The financial analysis provides information on financial attractiveness of an integrated biogas, latrine and hygiene program from the perspective of the consumer. The base case scenario assumes installation of improved pour-flush latrines among 50% of households in Uganda and Rwanda, 75% in Ethiopia, and 50% for Sub-Saharan Africa. The financial analysis was conducted for an "average" household, reflecting generalized conditions within each country. For example, if 25% of households purchase firewood and 75% collect, the analysis assumes that our average household purchases 25% of their firewood and collects the remaining. With these caveats in mind, the results for the base case scenario yield benefit-cost ratios (BCRs) ranging from 1.22 to 1.35 and financial internal rates of return (FIRRs) from 7.5% to 10.3%. Extensive sensitivity analysis was undertaken to evaluate these results. The cost of the biogas plant, latrine, and fuel expenditure savings have a significant impact on financial performance. For example, a 25% reduction in the cost of the biogas digester boosts the FIRRs to 15% to 20%. A similar effect is observed when the cost the latrine is reduced.

Summary of key findings by program

Program	Number of biogas plants	Number of latrines	FIRR*	EIRR
Sub-Saharan Africa	2,002,800	1,001,400	7.5%	178%
Uganda	20,000	10,000	8%	166%
Rwanda	15,000	7,500	9.5%	161%
Ethiopia	10,000	7,500	10.3%	78%

*Includes subsidy

The economic analysis provides information on the attractiveness of an integrated biogas, sanitation and hygiene program to society and includes the full range of costs and benefits associated with the program. In all, nine types of benefits are valued, ranging from fuel cost savings to health-related impacts to environmental impacts. For the base case scenario, the BCRs range from 4.52 to 6.84 and EIRRs from 78% to 178%. This means that every dollar invested in an integrated biogas, latrine, and sanitation program results in more than US$4.50 of economic benefits. An important component of the economic benefits is captured in the value of lives saved (VOSL) benefit, which is associated with reduced mortality that is expected to result from the program. When the VOSL benefit is excluded, the economic performance remains strong, yielding BCRs ranging from 3.05 to 4.56, or every dollar invested in the program results in more than US$3 of economic benefits.

The difference between the economic and financial performance, reflects the nature of the intervention; an integrated biogas and latrine program involves significant capital investment and generates expenditure savings (rather than income), while yielding a wide range of economic (rather than financial) benefits, such as improved health, increased availability of high-quality fertilizers, time savings due to the reduced drudgery associated with fuel collection, and environmental benefits. The multifaceted nature of these economic benefits have the potential to make progress simultaneously on a number of Millennium Development Goals (MDGs), thereby significantly improving the lives of poor African households. Women and children in particular, have the potential to be the greatest beneficiaries of the poor, because they disproportionately endure the drudgery of fuel collection and the negative health effects associated with spending hours breathing highly polluted air just to prepare their daily food for their families. Decision makers should consider the scope and extent of these benefits for improving the lives of poor African households; they provide a solid rationale for a subsidy for an integrated biogas, latrine, and sanitation program.

What is clear is that the cost of the biogas plant and the latrine will be a key determining factor in the willingness of poor African households to invest. Both the plant and the latrine represent significant capital investments for low income households. In particular, the estimated cost of the pour-flush latrine may be prohibitive for many households, particularly because improved sanitation yield does not directly generate income or reduce expenditures. Given the high cost of the pour-flush latrine and the significant benefits associated with improved sanitation, sector experts should try to identify ways to reduce the cost of the latrine. Decision makers may also want to consider subsidies for latrines as well as for biogas plants, perhaps tied to performance incentives. Furthermore, decision makers should consider identifying ways to leverage the substantial sanitation investment that will occur in Sub-Saharan Africa in the next decade. There is a considerable gap between MDG sanitation targets and progress toward achieving these targets. To address this gap, international donors and national governments are ramping up efforts to meet MDG targets. An integrated biogas, latrine, and hygiene program could help address this gap, while leveraging planned investment.

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Abbreviations and acronyms

ALRI	Acute Lower Respiratory Infection
BCR	Benefit Cost Ratio
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CO_2	Carbon Dioxide
EIRR	Economic Internal Rate of Return
FIRR	Financial Internal Rate of Return
GDP	Gross Domestic Production
GHG	Green House Gas
JMP	WHO/UNICEF Joint Monitoring Program
LPG	Liquefied Petroleum Gas
MDG	Millennium Development Goal
NPV	Net Present Value
O&M	Operation and Maintenance
PPP	Purchasing Power Parity
SSA	Sub Saharan Africa
UN	United Nations
VOSL	Value of Saved Life
WHO	World Health Organization

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1.0 Introduction

Placing low income households at the center of energy, sanitation, and hygiene interventions offers opportunities to address multiple development priorities effectively and simultaneously using integrated approaches. In Sub-Saharan Africa, the majority of poor households lack basic cooking facilities and even the most rudimentary latrine and engage in poor hygiene practices. An estimated 80—90 % of African households rely on traditional biomass fuel (such as firewood, charcoal, dung, and agricultural residues) to meet their daily cooking needs (WHO, 2000). Many of these same households lack access to sanitation. An estimated 72% of households have no access to improved latrines (JMP, 2004). Besides spending money and time for biomass fuels, the poor often pay with their health. Indoor air pollution due to cooking with biomass alone led to 392,000 deaths in Africa in 2000 (WHO, 2006c). As a result, poor families breathe polluted air from indoor cooking, drink-contaminated water from lack of access to adequate sanitation and often fail to practice basic hygiene, leading to more than 3.2 million deaths each year on a global basis.[1]. Household-level programs can prevent disease and death, because they are "effective, inexpensive, and rapidly deployable" (WHO, 2006a). Understanding the costs and benefits of household-level programs–at both the household and societal levels–are key to making rational, information-based decisions.

1.1 Objectives

The main goal of this study is to document and quantify the costs and benefits of the *Biogas for Better Life* Initiative—an integrated biogas, sanitation, and hygiene program. Costs and benefits are estimated at the household and societal levels, for the Sub-Saharan Africa initiative as a whole as well as for three county-level programs in Uganda, Rwanda, and Ethiopia, which are in varying stages of development. This analysis is intended to aid policy makers in their decision-making process with respect to biogas plant or other household energy interventions as well as sanitation and hygiene interventions. Individual households make decisions based on perceived costs and benefits to the household. It is therefore important for individual households to know whether switching from traditional cooking fuels to a biogas plant, with an attached latrine in some cases, is advantageous. The specific objectives of the study are grouped into two categories:

Household Perspective:

- To identify the total costs related to biogas plant installation at the household level, including costs related to installation of improved latrine and adoption of better hygiene practices for participating households
- To identify the total benefits resulting from biogas plant installation at the household level, including benefits related to installation of improved latrine and adoption of better hygiene practices for participating households

[1] 1.5 million resulting from indoor air pollution and 1.7 million due to diarrhea.

- To identify net benefits, benefit-cost ratios and financial internal rates of return resulting from biogas plant and latrine installations and improved hygiene practices per individual household.

Societal Perspective:

- To identify the total costs to society related to an integrated biogas, sanitation, and hygiene program
- To identify the total economic benefits to society related to an integrated biogas, sanitation, and hygiene program
- To identify net benefits, benefit-cost ratios and economic internal rates to society related to an integrated biogas, sanitation, and hygiene program.

1.2 Study limitations

For the purposes of this study, the financial and economic analysis was based on an "average" or typical household in each location. What does this mean? It means, for example, that in Uganda, if 25% of households purchase firewood and 75% collect, our "average" household is assumed to purchase 25% of their firewood and collect the rest. Averaging has implications for the both the financial and economic analyses. If we were to segment the potential market for biogas based on fuel source (collected vs. purchased) and estimate the financial returns for each of these markets, the internal rate of return for households that purchased fuel wood would be significantly higher than for those who collect. Further studies should consider market segmentation to more fully evaluate the financial and economic implications of the proposed program based on a range of different household types.

A secondary limitation of the study relates to the availability of data. The study relies on a range of secondary sources supplemented by primary data as needed and available given time constraints. Due to the paucity of data, numerous assumptions are made for the purposes of the analysis. For example, in a number of circumstances data were not available for Sub-Saharan Africa as a whole. Therefore, we used country-level averages for Sub-Saharan Africa. All assumptions made in estimating costs and benefits are described in the methodology. Readers are advised to consider these assumptions as they interpret the findings of this study.

Finally, this study has selected one plant size for each of the 3 countries and the sub-Saharan Africa. For the countries level analyses, the choice of plant size was identified by the country level feasibility studies. For example the most appropriate size for Rwanda is $6m^3$, however in practice various sized plants ($4m^3$, $6\ m^3$, $8\ m^3$, $10m^3$) may be installed depending upon the cooking and lighting needs of the household and availability of dung and water. The national biogas programs in the region may also promote larger sized plants as appropriate for institutions. However, this study has focused only on household biogas plants

2.0. Methodology

WHO has recently prepared guidelines on conducting cost benefit analyses of household energy interventions (Hutton and Rehfuess, 2006), as well as published global cost-benefit analyses on household energy interventions (Hutton et al, 2006) and water and sanitation technologies (Hutton et al, 2007, Hutton et al, in press). This study draws on these global guidelines and studies.

For any intervention to be successful, the targeted beneficiaries need to believe that incremental costs are worth paying in switching over to the new technology. Households will adopt new technologies if the perceived benefits of adoption are greater than the perceived costs, and if they can afford the upfront investment; hence the relevance of household-level cost-benefit analyses.

A cost-benefit analysis from the society's perspective is similarly expected to illustrate the overall benefits of an integrated biogas and sanitation program for the nation and reinforce justification for investment in these interventions at the policy-making level. Note here that, unlike other economic analysis, these analyses also take into account different opportunity costs (such as labor time spent collecting traditional fuels). Table 1 provides an overview of the various costs experienced in at the household and the society-level that are captured in this analysis.

Table 1: Costs and benefits of an integrated energy and sanitation intervention considered for household level and societal level analyses

Level of analysis	Costs	Benefits
Household-level analysis (financial)	✓ Cost of a biogas plant at the subsidized rate ✓ Cost of a pour-flush sanitary latrine ✓ Repair and maintenance costs of plant and latrine ✓ Cost of extra time consumed due to biogas installation ✓ Cost of extra time consumed due to biogas installation and adoption of improved hygiene practices ✓ Cost of hygiene materials purchased by the household ✓ Financing costs, if applicable	✓ Cooking and lighting fuel savings ✓ Time saving due to biogas ✓ Saving in household's health-related expenditures ✓ Income effects of improved health
Societal-level analysis (economic)	✓ Full cost of a biogas plant and latrine ✓ Repair and maintenance cost for biogas plant and latrine ✓ Cost of extra time due to biogas plant and latrine ✓ Cost of hygiene materials purchased by the household ✓ Technical assistance ✓ Program costs related to biogas and hygiene, including financing	✓ Cooking and lighting fuel savings ✓ Chemical fertilizer saving[2] ✓ Time saving due to biogas and latrine (fuel collection, cleaning and cooking, latrine access) ✓ Saving in all health-related expenditures ✓ Time savings due to improved health ✓ GHG reduction ✓ Local environmental benefits

[2] Given the very low levels of chemical fertilizer use, fertilizer cost savings are considered only as economic, rather than financial benefits.

To compare benefits and costs, a number of cost-benefit measures were estimated from both household financial and societal economic perspectives including financial and economic net benefits (NPV), cost-benefit ratios (BCR), and financial and economic internal rates of return (IRR). Sensitivity analysis was also conducted to evaluate the impact of uncertainty in key variables on the summary economic indicators.

We would also ideally want to analyze the differential impacts of the introduction of an integrated biogas and sanitation interventions on different population groups including different members of the household (e.g., women and children spend more time in the kitchen, because they are the biggest beneficiaries of biogas), by disaggregating the costs and benefits for these different population subgroups in the analysis; however, due to time and data constraints, this analysis is not included in the present study.

Program size and time horizon. The information for this study is based on a proposed large-scale integrated biogas and sanitation initiative for Sub-Saharan Africa and three country-level programs–Uganda, Rwanda, and Ethiopia, where feasibility studies have already been conducted. In Rwanda, a detailed implementation plan has also been developed. These studies suggest the following five-year programs for Uganda (20,000 plants), Rwanda (15,000 plants), and Ethiopia (10,000 plants) and 15-year program for Sub-Saharan Africa (2.1 million plants).[3] Proposed program roll-outs are shown in Table 2.

Table 2: Biogas Program Expansion for Uganda, Rwanda, Ethiopia country program and the entire Sub-Saharan Africa Initiative

Year	Number of households receiving biogas plant intervention			
	Uganda	Rwanda	Ethiopia	Sub-Saharan Africa
Year 1	300	150	200	800
Year 2	1,000	1,150	800	11,000
Year 3	3,000	2,300	2,000	47,000
Year 4	6,000	4,200	3,000	86,000
Year 5	9,700	7,200	4,000	130,000
Year 6				164,000
Year 7				210,000
Year 8				244,000
Year 9				278,000
Year 10				332,000
Year 11				281,000
Year 12				172,000
Year 13				47,000
Year 14				11,000
Year 15				800
Total (15 years)	**20,000**	**15,000**	**10,000**	**2,002,800**

[3] The initiative program roll-out assumes that these 2 million plants will be installed through 34 national programs, including 10 successful cases involving relative rapid uptake of biogas plants (~980,000 plants) and 24 partially successful programs, involving slower rates of biogas adoption (~1.1 million plants). The initiative roll-out period of 15 years reflects successive staggered implementation of 34 five-year programs.

The input data for most recent costs and benefits have been taken from national feasibility studies, regional data sets for Sub-Saharan Africa, the Nepal Biogas Support program, and other secondary sources. Costs and benefits are estimated on an annual basis; net present values and benefit-cost ratios with a 3% discount factor have been adopted in the analysis. Costs are estimated assuming a five-year program roll-out in Uganda, Rwanda, and Ethiopia and a staggered 15-year roll-out for the Sub-Saharan Initiative as a whole, as described in Table 2. The functional period for biogas plants is taken as a minimum of 20 years at the very least, and costs and benefits have been calculated based on this assumption.

2.1 Cost Estimation

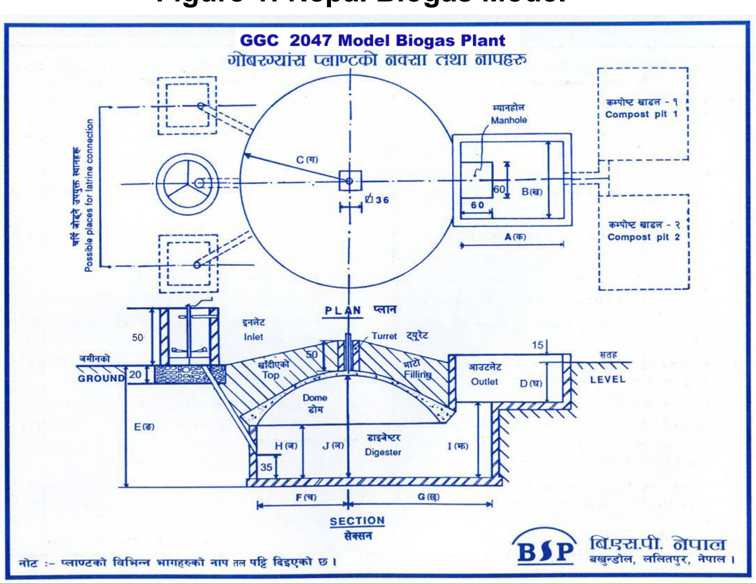
This section describes the methodology for estimation of financial and economic analysis of costs of the proposed intervention at the household and societal levels. Costs are estimated for the three main intervention areas relating to biogas plant, latrine, and hygiene.

2.1.1 Biogas plant-related costs

Biogas Technology. A biogas plant is an airtight container that allows fermentation of organic material under anaerobic conditions. Anaerobic digestion (fermentation) in the plant provides biogas as a clean and convenient fuel. It is mainly composed of 60–70% methane and 30–40% carbon dioxide. Biogas can be used for cooking and lighting, refrigeration, engine operation and electricity generation. In Sub-Saharan Africa, it is assumed that biogas will be used for both cooking and lighting given the low level of rural electrification.

Based on its success in Nepal and elsewhere and feasibility studies underway in Sub-Saharan Africa, the biogas plants to be constructed under the initiative are envisioned as a fixed dome model with the following characteristics (Figure 1):

Figure 1: Nepal Biogas Model



Characteristics

- Fixed dome (GGC Model 2047)
- Suitable as household-level plants
- Sized according to households needs of 4, 6, 8, and 10 cubic meters (digester volume)
- Uses cattle dung and water as raw materials for gas generation.

Financial Costs

Prior to the biogas intervention, households are assumed to use primarily traditional biomass (wood, dung and agricultural residues and charcoal) to meet household energy needs. Cooking and lighting with biogas will involve substantial incremental expenses compared to the status quo.

The financial costs of the biogas plant include the cost of the plant, annual repair and maintenance, and operation. The biogas plant cost has two components, one for capital investment during the year of installation and another for annual repair and maintenance cost. The expected life of the biogas plant is for at least 20 years[4] . The widely accepted fixed dome (GGC 2047) biogas plant model, with some modifications in the local context, will be promoted through this initiative. The resources required to construct a biogas plant, using an example of an $8m^3$ plant as proposed for Uganda, as shown in Appendix Table A.1.

The total cash costs for the biogas plant faced by the household equals the total cost of the plant less subsidies and in-kind contributions by the household plus annual maintenance and repairs. The capital cost of biogas plants varies with the size of plant, as well as availability of local materials. Based on the feasibility studies and other studies conducted, the most appropriate plant sizes are as follows: Uganda ($8m^3$),[5] Rwanda ($6m^3$), Ethiopia ($6m^3$), and the Sub-Saharan Initiative as a whole ($6m^3$). In-kind contributions are assumed to be 10% of the total capital cost. Because in-kind contributions do not involve cash outlays, they are considered an economic cost and are discussed in the economic cost section below. In addition to capital investment costs, households will also face annual repair and maintenance costs. As biogas is a proven technology in many Asian countries, it requires minimum repair and maintenance costs. The annual repair and maintenance cost is estimated at 1.5% of the total construction cost. The annual financial cost of operating a plant is assumed to be zero, because costs involve the labor to operate the plant and the collection of dung and water, which have little or no financial costs associated with them.[6]

Table 3 shows estimates of the net financial capital and annual repair and maintenance costs to the household. Table 4 extends household financial costs to program level, based on the estimated number of plants that will be installed in each of the countries and for the initiative as a whole.

[4] *Biogas as Renewable Source of Energy in Nepal Theory and Development,* 2005
[5] For Uganda, an $8m^3$ plant was deemed most suitable given larger household sizes and cooking and lighting needs.
[6] It is assumed that the water source for biogas plants will be nearly 100% from fetched/hauled sources in rural areas of Sub-Saharan Africa; therefore, there are no financial costs associated with purchased piped water, and instead, the water requirements are assumed to be met from household connections, nearby community point sources, or hauled water.

Table 3: Household-level financial costs of a biogas plant (US$)

Country/region	Average Plant Size	Total cost of the Plant	Proposed Subsidy	In-Kind Contribution	Annual repair and maint. Cost to households	Net Financial Capital Cost to household
Uganda	8m3	770	200	77	11.6	493
Rwanda	6m3	859	300	86	12.9	473
Ethiopia	6m3	747	186	75	11.2	486
Sub Saharan Africa	6m3	750	200	75	11.3	475

Table 4: Total Program-level financial costs of biogas plants (US$)

Country/region	Plant size	Targeted number of plants	Unit net capital cost per plant	Annual repair and maint. cost to households	Total cost financial costs
Uganda	8m3 plant	20,000	493	11.6	14,480,000
Rwanda	6m3 plant	15,000	473	12.9	10,962,000
Ethiopia	6m3 plant	10,000	475	11.2	7,059,241
Sub Saharan Africa	6m3 plant	2,002,800	475	11.3	1,401,960,000

Economic Cost

The economic costs of the biogas plant include the total financial costs plus:

- Value of in-kind contributions of households for the plant
- Value of household time to operate the plant, including collection of water and dung
- Cost of the subsidy
- Cost of program management and technical assistance.

The first two economic costs are incurred at the household level, whereas the latter economic costs are incurred at the program level.

Value of in-kind household contributions. Households typically provide contributions of unskilled labor and locally available materials (such as sand and water) for construction of the plant. The in-kind contributions will depend on availability of local materials and may vary in different locations. Households generally, can contribute unskilled labor for digging the pit and helping mason, as well as collect sand and gravel if available in their locality. In-kind contributions are often a requirement associated with receiving a subsidy for the plant. This study, assumes an in-kind contribution equal to 10% of the total capital cost.

Value of time for operation. Using biogas to meet household energy needs results in time spent on biogas-related activities, such as water and dung collection and mixing of cow dung and water. Time spent collecting water, and dung and operating the plant has a value–the opportunity cost of time that could have been used for other productive, but non-income-generating activities. In some cases, the value of this time has financial value, if time is used for operation of the plant, instead of income-generating activities; however, here we consider only the economic value of time.

Water collection times. Daily water collection times per household in rural areas vary from around 0.5 to several hours (Hutton et al, 2006). In Rwanda, an average of 2.8 hours is spent collecting water a week in rural areas (Living Conditions Survey). In Uganda, 75% of households collect water from within 1 km and the rest from more than 1 km (Uganda Bureau of Statistics, Population and Housing Census, 2002). In Ethiopia, 64% of rural households live within 1 km of a water source and 36% more than 1 km. These national surveys are supported by a large study from East Africa (Thompson et al. 2003), which reports that the average distance to water sources in rural areas of Uganda, Kenya, and Tanzania is 622 meters, which is a more than 30-minute round trip. These figures exclude waiting time at the water source, which is conservatively assumed to be zero. A conservative assumption, therefore, for the average distance to haul water is 1 km with a round-trip time of 30 minutes and two journeys per day to collect 60 liters for the household. Combining these data, an estimated collection time is roughly 1 minute per liter each day.

Dung collection and mixing times. The program will target households with livestock nearby and dung is assumed to be readily available to the household, thus time is estimated jointly for mixing of dung and collected water. Time required for the mixing of water and dung is taken from the Biogas Users Survey in Nepal. It is estimated that a household spends 0.25 hours a day mixing water and dung to feed the biogas plant.

Value of time. The economic value of the time is approximated by the rural wage rates for unskilled workers. Based on field data, the hourly-equivalent agricultural wage rates are as follows: Uganda US$0.22, Rwanda US$0.25, Ethiopia US$0.21, and Sub-Saharan Africa US$0.23. Using the value of paid labor assumes that such work is actually available, which it may not be, or it may only be seasonal in nature. The sensitivity analysis evaluates the influence of the value of time on net returns.

Subsidies. Although a biogas plant provides a number of benefits to the household, one of the barriers to installing the biogas plant is its upfront cost. Subsidies provided by the national program will reduce the upfront burden to the farmer. The *Biogas for Better Life Initiative* is being designed to provide around one-third of the cost as subsidy. The actual subsidy is expected to vary from country to country, based on capital costs and other local conditions. The proposed subsidy for the three-country program and the initiative as a whole were presented in Table 3. These subsidies levels were determined based on feasibility studies undertaken in each country and for the initiative as a whole.

Program management and technical assistance cost. Large-scale dissemination and installation of biogas plants needs organized national programs and technical assistance from the institutions with experience and expertise in this sector. Program and technical assistance cost is also considered an economic cost of the plant. Table 5 provides estimates of program and technical costs per household based on country- and initiative-level feasibility studies.

Table 5: Program cost and Technical Assistance (US$)

Country/region	Cost per household	Number of households	Total cost
Uganda	202	20,000	4,040,000
Rwanda	155	15,000	2,325,000
Ethiopia	389	10,000	3,890,000
Sub Saharan Africa	140	2,002,800	280,392,000

Total economic costs of associated with biogas plant. The total economic costs for the biogas capital costs (including subsidy), annual maintenance and repair, and program and technical assistance costs are shown in Tables 6 and 7. Table 6 shows the components of plant-related costs on a per household basis. Table 7 shows costs on a programmatic basis, which total more than US$4.3 billion for the Sub-Saharan Africa initiative.

Table 6: Components of economic cost per household reached including full capital cost of plant, annual maintenance and repair and program and technical assistance costs (US$)

Country/region	Full economic capital cost (incl. subsidy)	Annual maint. & operation cost	Program and technical assist. Cost
Uganda	770	63	202
Rwanda	859	66	155
Ethiopia	747	62	389
Sub Saharan Africa	750	63	140

Table 7: Total biogas plant-related economic cost of per program: full capital cost of plant, annual maintenance and repair and program and technical assistance costs (US$)

Country/ region	Targeted number of plants	Total Subsidy	Full economic capital cost including subsidy	Program and technical assist. cost	Total Economic Cost
Uganda	20,000	4,000,000	40,590,809	4,036,473	44,627,282
Rwanda	15,000	4,500,000	32,628,000	2,331,357	34,959,357
Ethiopia	10,000	1,860,000	19,882,890	3,891,735	23,774,625
Sub Saharan Africa	2,002,800	400,560,000	4,025,197,165	280,860,244	4,306,057,409

2.1.2 Latrine-related costs

Evidence from Nepal and elsewhere have demonstrated that attaching sanitary latrines to biogas plants contribute significantly to better health and hygiene in rural communities. The contribution of night soil, or human feces, to biogas generation, however, is minimal.

Latrine technologies and installation. A pour-flush latrine may be attached to a biogas plant. In an attached latrine, human waste is flushed through a tube directly into the biogas digester. The latrines to be constructed under the initiative will be a pour-flush model. Resource examples required to construct a pour-flush latrine are shown in Appendix Table A.2.

2.1.2 Latrine-related costs

Financial costs

The household financial costs of an improved latrine consist of the price paid for the initial investment and, on a recurrent basis, the price paid, if applicable, for water for flushing the human waste into the biogas plant. Not all households receiving the biogas plant intervention will, however, choose an improved latrine or a latrine with connection to the plant. Some may choose to invest in an improved latrine a year or two after they install the plant. The financial cost to those households that do install a latrine include the price paid for the latrine by the household, which will depend on local economic conditions, less in-kind contributions (labor and materials) and the subsidy paid for by the government or donor (if any). This study assumes an in-kind contribution equal to 10% of the capital cost for a latrine. In addition, households may face financing costs if a loan must be taken to finance the latrine; however, these costs are not included in the analysis.

The estimated life of a pour flush latrine is seven years, so households who opt to install a latrine must purchase a replacement every seven years after installation. This means that during the 20-year lifespan of a biogas plant, a new latrine must be purchased twice (i.e., after seven and 14 years). No ongoing maintenance of the latrine is realistically assumed; hence, the relatively short life span of seven years. The water source for pour-flush toilets will be close to 100% from fetched/hauled sources in rural areas of the three countries; therefore, no financial costs are associated with purchased piped water; instead the water requirements are assumed to be met from household connections, nearby community point sources, or hauled water.

Table 8 shows the estimated net financial costs for a pour-flush latrine incurred by participating households. Costs for the latrines were based on field data collected for the analysis in Uganda, Rwanda, and Ethiopia. While these cost estimates seemed unusually high, they were the data provided to us from the field. For Sub-Saharan Africa, the total cost of a pour-flush latrine was assumed to be US$200, based on country-level estimates that were provided. For the purposes of this analysis, no subsidy for the latrine is assumed. Given the expected health benefits associated with improved sanitation, however, the sensitivity analysis evaluates the effect of a subsidy equal to 30% of the capital cost of the latrine.

Table 8: Household level financial costs of a pour-flush latrine (US$)

Variable	Price in US$ (2006 values)			
	Uganda	Rwanda	Ethiopia	Sub Saharan Africa
Total cost of the latrine	284	255	200	200
Less: in-kind contribution of materials and labor from household	28.4	25.5	20	20
Net financial costs to the household	255.6	229.5	180	180

The program-level financial cost of the latrines depends on the total number installed and the level of subsidy, which is presumed to be zero. To estimate latrine adoption rates, current levels of sanitation coverage, the target population for the initiative, and the cost and experience of adoption of pour-flush latrines in the Nepal biogas program were considered. According to data available from the WHO/UNICEF Joint Monitoring Programme (JMP), improved sanitation[7] coverage rates vary significantly from country to country in Sub-Saharan Africa (WHO/UNICEF/JMP, 2006). In Ethiopia, more than 90% of rural households lack access to improved latrines and 79% of total households use open defecation as their main sanitation option. In Uganda, 59% of rural households do not have an improved latrine, and in Rwanda the figure is 63%; however, other national figures paint a different picture. For example, in Rwanda, the integrated living conditions survey 2005–06 showed 55% of rural households having an enclosed pit latrine, 38% an open pit latrine, and 7% no latrine. For Sub-Saharan Africa, JMP figures show that 72% of the rural population is not served.

In estimating how many households may invest in a new improved latrine, it should be recognized that the targeted households for biogas plants will not necessarily be "average" rural households. Given the costs of adopting a biogas digester, the households who adopt a biogas plant will likely be of a higher economic status and they are, therefore, more likely to already have an improved latrine. It is possible, however, that even those with improved latrines may invest in a connection, or may rebuild their latrine to bring it closer to the plant. Indeed, this has been the case in Nepal and elsewhere in Asia, where more than 90% of households with biogas plants have attached latrines. Adoption of attached pour-flush latrines grew gradually during the program as households became more familiar with them.

Given the above considerations and further field research conducted by the country teams for Uganda, Rwanda and Ethiopia, the analysis therefore assumes that, in Rwanda and Uganda, by the end of the five-year program, 50% of households investing in a biogas plant will also have invested in a compatible (connecting) latrine. For Ethiopia, given the very low latrine coverage rates, it is assumed that three-quarters (75%) of households will invest in a new improved pit latrine during the life of the program. For Sub-Saharan Africa, it is assumed 50% of households

[7] According to the Joint Monitoring Programme, improved sanitation includes simple pit latrines, ventilated improved pit latrines, pour-flush latrines, connection to a septic system, and connection to a public sewer. Unimproved latrines include bucket latrines, public or shared latrines, and open pit latrines; however, in Sub-Saharan Africa, many households have no latrines and rely on "open defecation."

will invest in a new improved pit latrine during the life of the program. Table 9 shows the total financial costs for the latrines during the life of the programs.

Table 9: Total program-level financial costs of pour-flush latrines (US$)

Country/Region	No. of latrines installed over the program life	Financial Cost
Uganda	10,000	7,668,000
Rwanda	7,500	5,163,750
Ethiopia	7,500	4,050,000
sub-Saharan Africa	1,001,400	580,248,000

Economic costs.
In addition to the household financial costs described above, other costs must be taken into account to reflect the full societal economic cost. Household-level economic costs include financial costs plus the value of in-kind contributions for construction of the latrine and time spent collecting water. As described above, the in-kind contribution of the household to labor and materials is assumed to be 10% of the capital cost for the latrine. Because the water used for the pour-flush latrine enters directly into the biogas plant and, therefore, reduces the required water inputs, the value of time for water collection for the latrine is included in the economic value of water hauled for biogas plant operation.

Program-level economic costs include household-level economic costs plus the program costs for implementing the latrine program. Given the paucity of data on latrine program costs, the assumed cost per household targeted for the latrine program is US$2. Should a latrine subsidy be offered, it would constitute an additional program-level economic cost. Table 10 shows the total economic cost for the latrine program.

Table 10: Program level economic costs for latrine capital and program costs (US$)

Country/Region	Number installed	Total Economic Cost
Uganda	10000	8,580,000
Rwanda	7500	5,782,500
Ethiopia	7500	4,545,000
Sub-Saharan Africa	1201680	651,167,200

2.1.3 Hygiene costs

Hygiene intervention will take place at both the household and societal levels. The costs at the household level will be for hygiene materials, whereas at the societal level the costs are for program management.

Financial costs

Household financial costs of the hygiene intervention consist of the recurrent costs of purchasing hygiene materials, in particular, soap and cleaning materials. Hygiene covers the appropriate handling of human and animal waste and improved personal hygiene standards and cooking hygiene. The hygiene intervention program involves basic hygiene education. It is assumed to be provided to all households receiving a biogas plant and is paid for by the program financier. Prior to the program, it is assumed that all households did not previously engage in hygiene activities properly; however, given that hygiene practices may involve some time or financial costs, not all households will comply with the improved hygiene practices. For the purposes of the analysis, it is assumed that 60% of households comply with the practices promoted by the hygiene program.

Given the paucity of data on household expenditure for hygiene-related materials, the costs of compliance are taken from a study in Burkina Faso that measured household expenditure on hygiene materials, estimated at US$8 per household per year (Borghi et al). Thus, the household financial cost is US$8/year for the 60% of households practicing improved hygiene, and US$0 for the 40% of households who do not practice improved hygiene.

The program-level financial costs for the program include the hygiene materials cost for the 60% of all households participating, as shown in Table 11.

Table 11: Financial costs for hygiene intervention at the program level (US$)

Country/Region	Number of households adopting improved hygiene practices	Financial Cost
Uganda	12,000	96,000
Rwanda	9,000	72,000
Ethiopia	6,000	48,000
Sub-Saharan Africa	1,201,680	9,613,440

Economic costs

At the household level, the economic costs include the financial costs for hygiene materials for households who adopt improved hygiene practices, plus the value of time spent in hygiene activities. The time spent per day on hygiene activities is not available from any literature or field sources and is estimated at 8 minutes per household per day. This consists mainly of hand washing, but can also include toilet cleaning. The economic value of time is approximated, based on rural wage rates for unskilled workers, as described above, using the following rates: Uganda US$0.22 per hour, Rwanda US$0.25, and Ethiopia US$0.21, and Sub-Saharan Africa US$0.23. Table 12 shows the annual economic costs per household for those participating in the program.

At the societal level, the economic costs will also include the program cost per household reached (all households), in addition to the financial costs. It is assumed that the program costs are incurred only during the lifetime of the program (5 years). Estimates of the costs of hygiene education programs are provided by international literature.[8] Research in Burkina Faso by Borghi et al (2002) showed a cost US$4.54 per household for a hygiene program during a period of 3 years (Borghi et al 2002). Other sources in the literature state slightly higher costs, but the Borghi estimate of US$4.54 per household has been selected here, because it is considered the most reliable, because it was based on primary field data collection.

Table 12: Annual economic costs incurred by participating households for improved hygiene US$

Country/Region	Hygiene materials cost	Value of time for hygiene practices	Annual economic cost per participating household
		US$	
Uganda	8	10.71	18.71
Rwanda	8	12.17	20.17
Ethiopia	8	10.22	18.22
Sub-Saharan Africa	8	11.19	19.19

2.1.4 Uncertainties in costs

There are various uncertainties in cost quantification, which may affect the result. Some probable uncertainties in cost analysis may arise due to the following:

- Consideration by the study of only the most common size for plants, so these are the average costs.
- Dissimilar availability of local materials in various places, even within a country.
- Differences in transportation cost of raw materials for plant installation at different locations.
- Costs of hygiene and latrine programs.

In the analysis are considered to represent averages; hence, no further analysis has been done to explore the effects of these uncertainties.

2.2 Impact Estimation

The integrated household-level biogas, sanitation, and hygiene initiative is expected to generate significant direct and indirect benefits for both households and society in general. To understand better the nature and extent of these benefits, the financial and economic value of a range of

[8] In Zimbabwe a hygiene intervention cost of US$1.40 per capita, including program and recurrent costs (Waterkeyn 2003). A generalized developing country estimate of US$3 per household for program costs was made by Varley et al 1998. A second generalized developing country estimate was estimated at US$1 per capita (Cairncross 2006).

identified direct and indirect benefits are estimated. This section describes the methodology used for the financial and economic analysis of impacts of the proposed intervention at the household and societal levels.

Biogas is not noxious; it is colorless and odorless, and is an ideal fuel that can be used for a variety of applications, such as cooking, lighting, and power. The substitution of highly polluting traditional fuels with biogas virtually eliminates indoor air pollution, which is a major cause of acute lower respiratory disease, particularly among women and children who spend large amounts of time in smoke-filled kitchens, as well as other diseases such as chronic obstructive pulmonary disorder (Bruce et al., 2006). The spent waste that comes from the biogas plant after the gas is produced is excellent organic manure that augments soil fertility. By coupling the biogas plant with latrine and hygiene interventions, the health benefits of biogas are enhanced. In addition to the high-quality cooking and lighting fuel and health benefits, an integrated biogas and sanitation program offers a number of direct and indirect benefits, including time savings associated with fuel wood collection and cleaning, as well as environmental benefits through reduction local deforestation and greenhouse gas emissions.

This study estimates the financial and economic value of ten types of impacts associated with an integrated biogas, sanitation, and hygiene program:

- Fuel cost savings
- Savings in cooking and cleaning time
- Latrine access savings
- Fertilizer use benefits
- Health expenditure savings
- Health-related productivity
- Value of saved lives
- Lighting benefits
- Global environmental benefits associated with reduction in greenhouse gas emissions
- Local environmental benefits associated with reduction in deforestation due to substitution of biogas for fuel wood.

2.2.1 Fuel cost savings

The major financial impact of the biogas plant is the reduction in expenditure for traditional fuels, which would otherwise be incurred in its absence.

Financial benefits

At the household level, financial benefits result from actual cash savings due to reduced purchases of cooking fuel as well as to increases in income associated with productive time reallocated from collection of fuel wood to income-generating activities.

Savings due to reduced purchases of cooking fuel. The financial value of fuel expenditure savings is estimated based on the following five variables:

- Percentages of purchased fuels by households by type of fuel
- Amount of each fuel type used annually per household
- Amount of fuel purchased vs. collected for each fuel type

- Cost of purchased fuels by type
- Expected percent reduction in each fuel type due to adoption of a biogas plant

Table 13 shows the percentages of households using various cooking fuels for the three countries and Sub-Saharan Africa. The majority of purchased fuel is firewood (80–90%) combined with a modest amount of charcoal in Uganda (15%) and Rwanda (7%).

Table 13: Purchased fuel by households: percentages of purchased fuel by type

Variable	Fuel type	Uganda	Rwanda	Ethiopia	Sub-Saharan Africa
purchased fuel (% by type)	Elec., LPG, Kerosene	2.3		1.4	1
	Charcoal	15.4	7.4	1.3	5
	Firewood	81.6	90.4	81.4	88
	Other (ag residues)	0.6	2.2	16	6

Sources: Uganda: Population and Housing Census, 2002; Rwanda: Population and Housing Census, 2002; Ethiopia: EREDPC, 1999; Sub-Saharan Africa: Due to lack of regional data, an average of three countries is assumed.

Uganda. Annual charcoal consumption for Kampala is 190 kg per capita, and fuel wood consumption for rural areas is 616 kg per capita (Ministry of Energy and Mineral Development, 2003 as cited in the Winrock Uganda Biogas Desk Study, 2006). With an average household size of five in Uganda, annual household consumption of charcoal and firewood is estimated at 950 kg (2.6 kg/day) and 3,080 kg (8.4 kg/day), respectively. Field surveys indicate that 25 percent of households purchase firewood and the remainder collect. According to the field survey conducted during the feasibility study for Uganda, the average market price for firewood is US$0.06/kg and for charcoal is US$0.14/kg (Uganda feasibility study, 2007). As all the cooking needs will not be fulfilled by the use of the biogas plant, it is estimated that there will be a reduction of 90% in charcoal consumption and 75% in firewood consumption after the installation of a biogas plant. Based on these estimates, an average household in Uganda will save US$46.7 a year in cooking fuel expenditures with installation of a biogas plant (Table 14).

Rwanda. The annual charcoal consumption per capita per day for Rwanda is 0.48 kg and the firewood consumption per capita per day is 1.45 kg. With an average household size of 4.52, the annual per household charcoal consumption is 792 kg (2.17 kg/day) and the annual per household firewood consumption is 2,392 kg (6.55 kg/day), based on field survey data. Field surveys also indicate that 20 percent of households purchase firewood and the remainder collect. According to field surveys, the price of charcoal is US$0.27/kg and firewood is US$0.07/kg. As all the cooking needs will not be fulfilled by the use of the biogas plant, it is estimated that there will be a reduction of 90% in charcoal consumption and 75% in firewood consumption after the installation of a biogas plant. Based on these estimates, a household will save, on average, US$36.9 per year in cooking fuel expenditures with the installation of biogas plant (Table 14).

Ethiopia. Field surveys carried out as part of the Ethiopia feasibility study estimate the annual charcoal consumption at 219 kg (0.6 kg/day) per household, based on field data, which seems relatively lower than its neighboring countries; however, annual firewood consumption is estimated at 4,570 kg (12.52 kg/day) per household, which is relatively higher than neighboring countries. Field survey data indicate that 25 percent of households purchased firewood and the remainder of households collect. The Ethiopia feasibility study reports the price of charcoal at US$0.18/kg and firewood at US$0.08/kg. As all the cooking needs will not be fulfilled by the use of the biogas plant, it is estimated that there will be a reduction of 90% in charcoal consumption and 75% in firewood consumption after installation of a biogas plant. Based on these estimates, a household will save, on average, US$56.26 a year in cooking fuel expenditures with installation of biogas plant (Table 14).

Table 14: Household fuel consumption, purchases, prices and savings

Variable	Fuel type	Uganda	Rwanda	Ethiopia	Sub-Saharan Africa
Distribution of Households by fuel type	Elec., LPG, Kerosene	2.30%		1.40%	1%
	Charcoal	15.40%	7.40%	1.30%	5%
	Firewood	81.60%	90.40%	81.40%	88%
	Other	0.60%	2.20%	16%	6%
	Total	**100%**	**100%**	**100%**	**100%**
% of households using purchased fuel*	Elec., LPG, Kerosene	2.30%	0.00%	1.40%	1.00%
	Charcoal	15.40%	7.40%	1.30%	5.00%
	Firewood	20.40%	18.08%	20.35%	22.00%
	Total	38.10%	25.48%	23.05%	28.00%
% of Households collecting firewood		**61.8%**	**74.5%**	**77.1%**	**72.0%**
Total annual household fuel consumption (kg/yr)	Charcoal	950	792	219	690
	Firewood	3080	2392	4570	2920
% reduction in fuel purchases w/ biogas plant	Charcoal	90%	90%	90%	90%
	Firewood	75%	75%	75%	75%
Amount of fuel purchases avoided w/ plant (kg/yr)	Charcoal	131.7	52.7	2.6	31.1
	Firewood	471.2	324.4	697.5	481.8
Unit cost to households (US$/kg)	Charcoal	US$0.14	US$0.27	US$0.18	US$0.27
	Firewood	US$0.06	US$0.07	US$0.08	US$0.04
Annual household financial fuel savings	Charcoal	US$18.43	US$14.24	US$0.46	US$8.38
	Firewood	US$28.27	US$22.70	US$55.80	US$19.27
	Total	**US$46.71**	**US$36.95**	**US$56.26**	**US$27.66**

* This is the percent of the households using purchased cooking fuel: electricity, LPG, kerosene or charcoal or firewood.

Note: Considering a single household using charcoal, for example, savings of the household from reduced charcoal use will be 855 kg in Uganda; however, the table shows that it will be 131.67 kg, because only 15.4% households are assumed to use charcoal in Uganda. All the electricity, LPG, kerosene, and charcoal are purchased fuel Among the firewood users, 25% of households in Uganda, Ethiopia, and Sub-Saharan Africa and 20% of households in Rwanda use purchased fire wood.

Sub-Saharan Africa. Annual household charcoal and firewood consumption figures are based on estimates by WHO (2006) as follows: charcoal consumption is 690 kg (1.9 kg/day) and firewood consumption is 2,920 kg (8 kg/day). Based on field survey results from the country-level studies, it is assumed that approximately 25 percent of households purchase firewood and the remainder collect. The WHO study reports the price of charcoal in Sub-Saharan Africa as US$0.3/kg in urban areas and US$0.24/kg in rural area. This analysis assumes an average charcoal price of US$0.27/kg. The same study reported the price of firewood as US$0.05/kg in urban areas and US$0.03/kg in rural areas. This study assumes an average price for firewood of US$0.04/kg[9]. As all the cooking needs will not be fulfilled by the use of the biogas plant, it is estimated that there will be a reduction of 90% in charcoal consumption and 75% in firewood consumption after the installation of a biogas plant. Based on these estimates, an average household in Sub-Saharan Africa will save US$30.6 per year in cooking fuel expenditures with the installation of a biogas plant (see Table 14).

Income generated from fuel collection time savings. For households that collect firewood, a biogas plant will result in significant time savings. A portion of this time savings is assumed to be used for income-generating activities. As a biogas plant reduces firewood consumption by an estimated 75%, a concomitant 75% savings in firewood collection time is assumed. Considering the limited income-earning opportunities in the Sub-Saharan African region only an estimated 20% of the saved time will be used for income-generating activities. In recognition that fuel wood collection is done primarily by women and children, one-half of the collection time is conservatively estimated to be attributable to women and valued at the unskilled agriculture wage rate. The other half of collection time is estimated to be attributable to children and the value of their time at zero. This effectively means that only 10% of saved time will be used for income-generating activities.

- For Uganda, field surveys undertaken as part of the feasibility study indicate that an average household spends 0.9 hours per day in collecting firewood. In total, 38% households use purchased fuel for cooking and 62% collect firewood. For those households who collect, a biogas plant will reduce firewood collection time by 75%. Considering 10% of the saved time is used by adults in generating income, a biogas plant creates additional income of US$3.15 per year due to time savings associated with reduced firewood consumption (Table 15).
- For Rwanda, the average household that collects fuel wood spends 1.4 hours a day collecting firewood. An estimated 75% of households collect firewood. For those households that collect, a biogas plant will reduce firewood collection time by 75%. Considering 10% of the saved time is used by adults in generating income, a biogas plant results in additional income of US$7.20 a year due to time savings associated with reduced firewood consumption (Table 15).
- For Ethiopia, households that collect fuel wood spend approximately 1.3 hours a day doing this work. For the estimated 77% of households in Ethiopia who collect firewood, a biogas plant would reduce firewood collection time by 75%. Assuming 10% of time savings is used for income-generating activities by adults, a biogas plant creates additional income of US$5.20 per year (Table 15).
- For Sub-Saharan Africa, the average collection time for firewood is 1.2 hours per day. An estimated 71% of households use the collected firewood; thus, adopting a biogas plant

[9] Evaluation of the cost and benefits of household energy and health interventions at global and regional level, WHO, 2006

would result in fuel wood collection time savings of 71%. For those households who collect, a biogas plant would reduce firewood collection time by an estimated 75%. Assuming 10% of the saved time is used by adults in generating income, a biogas plant creates additional income of US$5.10 per year (Table 15).

Table 15: Household-level financial and economic value of time savings used for income generation

	Uganda	Rwanda	Ethiopia	SSA
% of households collecting fuel wood	62%	75%	77%	71%
Average time spent in collecting fuel wood (hrs/day)	0.9	1.4	1.3	1.2
Reduction in fuel wood collection	75%	75%	75%	75%
Value of time (US$/hr)	US$0.22	US$0.25	US$0.21	US$0.23
Financial benefit US$/yr	US$3.15	US$7.20	US$5.20	US$5.10
Economic benefit US$/yr	US$15.70	US$36.40	US$26.00	US$25.50

The total financial benefits associated with fuel cost savings range from US$12 million to US$19 million for the national program and exceed $US1.4 billion for Sub-Saharan Africa (Table 16).

Economic benefits

At the household level, the economic benefits of fuel cost savings include the financial benefits plus the *total* value of time savings due to reduced firewood consumption and associated labor, as well as time savings for cooking and for cleaning utensils. Table 15 shows the annual economic value of time savings associated with fuel wood collection for those households that collect.

In addition to time savings associated with fuel collection, biogas stoves also generate economic benefits as a result of time savings associated with cooking and cleaning. Biogas stoves have higher combustion efficiency compared with traditional biomass and fossil fuel stoves. A biogas stove is 1.07 times more efficient than an LPG stove, 1.22 times more efficient than a kerosene stove, 4.63 times more efficient than a traditional agricultural residue–burning stove, and 6.52 times more efficient than traditional dung-burning stoves in terms of heat output (Smith K.R et al, 2000*)*. This increased efficiency leads to substantial time savings for rural women. The biogas users' survey in Nepal suggests that biogas users save an average of 96 minutes a day for cooking compared with traditional stove users. Furthermore, biogas is a clean cooking fuel, which results in time savings for washing cooking utensils by an estimated 39 minutes per day on average.

As biogas is a proven technology, the functional rate of a biogas plant for the Africa region is considered to be 95%. Under this assumption, it is estimated that 95% of the households installing a biogas plant will use it for cooking and will enjoy the benefits of time saved from cooking and cleaning. For Uganda and Rwanda, it is assumed that households will save 96 minutes for cooking and 39 minutes for cleaning time every day (based on Nepalese data). In Ethiopia, the field survey data suggest time savings for cooking and cleaning of 96 minutes and 37 minutes, respectively. For Sub-Saharan Africa, an average of the three countries is assumed. Based on the above, the annual economic value of savings per household associated with cooking and cleaning are as follows: Uganda (US$84.50), Rwanda (US$97.50), Ethiopia (US$71.40) and Sub-Saharan Africa (US$84.40).

Total economic value of fuel expenditure and time savings

The total economic benefits associated with fuel cost expenditure and time savings are shown in Table 16. The value of fuel expenditure savings constitutes the majority of these estimated benefits. Economic benefits range from US$30 million to US$58 million for national programs and exceed US$5.6 billion for the Sub-Saharan initiative as a whole. The variation in country-level benefits reflects differences in the distribution of cooking fuels used, local fuel prices, and time spent collecting fuel wood.

Table 16: Total Financial and economic benefits of fuel cost savings (US$)

Country/ Region	Financial Benefits	Economic Benefits
Uganda	19,942,620	58,803,140
Rwanda	13,269,761	51,269,585
Ethiopia	12,046,375	30,734,327
Sub Saharan Africa	1,431,895,357	5,631,591,323

2.2.2 Latrine access savings

Latrine access savings are mainly economic in nature, although time savings may be used for income-generating activity. A potential financial cost saving—that of reduced payment for access to public toilets—is unlikely to be relevant in this study, because rural areas of the three countries have very few public toilets, let alone ones where fees are paid. Households who gain from less access time are those that spend time accessing latrines away from their place of living or work, such as associated with public latrines or open defecation. The time savings that accrue to households installing latrines has both financial and economic value. A portion of this time savings is assumed to be used for income-generating activities. Considering the limited income-earning opportunities in the Sub-Saharan African region only 20% of the saved time is estimated to be used for income-generating activities.

This study assumes that half (50%) of the households receiving an improved latrine in Uganda and Rwanda cease to practice open defecation. Given the apparently common practice of open defecation in Ethiopia, it is assumed that 75% of those receiving improved latrines cease to practice open defecation in Ethiopia. For Sub-Saharan Africa, the figure is assumed to be 50%. The access time per day to a site of open defecation depends on time per visit and visits per day. Hutton and Haller (2004) assume 30 minutes per person per day can be saved by building a latrine in or next to the home area. No other data are available on this variable; hence, in line with the Hutton and Haller study, it is assumed that the visit time per round trip is 12 minutes and three journeys are made per person per day. As program coverage is provided on the household level, the latrine time access savings should be multiplied by the average household size in rural areas, which is taken as five in Rwanda, Ethiopia, and Sub-Saharan Africa, and six in Uganda. The time gained is multiplied by the economic value per hour. As elsewhere in this study, time is valued at the unskilled rural wage rate. Based on field data, the hour equivalent agricultural wage rates are as follows: Uganda US$0.22 per hour, Rwanda US$0.25, Ethiopia US$ 0.21, and Sub-Saharan Africa US$0.23. Table 17 shows the total financial and economic benefits associated with latrine access savings.

Table 17: Economic Latrine access savings (US$)

Country/Region	Financial Benefits	Economic Benefits
Uganda	5,696,532	56,965,318
Rwanda	4,927,500	41,062,500
Ethiopia	3,589,084	30,519,426
Sub Saharan Africa	572,454,980	4,770,458,166

2.2.3 Fertilizer use benefits

Biogas slurry, a by-product of biogas, is a high-quality organic fertilizer and conditioner for the soil that surpasses farmyard fertilizer. If composted properly, the slurry will give higher yields of superior quality fertilizer and can increase crop production, thereby augmenting income. Simultaneously, as it replaces chemical fertilizers, the slurry saves the money previously spent on chemical fertilizers. Given the very low levels of chemical fertilizer use in Sub-Saharan Africa, fertilizer cost savings are considered only as economic, rather than financial, benefits.

Table 18 shows the annual production of slurry fertilizer by nutrient content, generated as a by-product from biodigestion of farmyard waste, for a range of biogas plant sizes.

Table 18: Additional Soil Nutrients from Slurry

Size of Plant	4m3	6m3	8m3	10m3
Nitrogen (Kg/year)	44	66	88	110
Phosphorous (kg/year)	60	90	120	151
Potash (kg/year)	46	69	92	115

Source: Physiochemical study of Bio slurry in Nepal, 2006

Economic benefits

The economic value of slurry is estimated using the current market prices for fertilizer. Table 19 shows the prices of equivalent chemical fertilizers. Prices for each country were collected during field surveys undertaken as part of the feasibility studies. Prices for Sub-Saharan Africa are an average of the country estimates. The equivalent market of sludge ranges from US$187–US$463 per year per plant, with variations attributable to difference in local fertilizer prices. To estimate the total economic value of slurry, it is assumed that 80% of the households installing a biogas plant will use slurry as a fertilizer for their farm. The economic value of total fertilizer benefits are presented in Table 20.

Table 19: Prices for fertilizer and market value of sludge ($US)

Variable	Uganda	Rwanda	Ethiopia	SSA
Nitrogen	1.13	1.13	0.85	1.04
Phosphorous	2.10	2.10	0.82	1.67
Potash	1.21	1.21	0.83	1.08
Equivalent (market) value of sludge available (US$/year/plant)	463	347	187	294

Sources: country-level feasibility studies

Table 20: Total economic benefits slurry fertilizer (US$)

Country/Region	Economic Benefits
Uganda	148,076,310
Rwanda	83,292,924
Ethiopia	29,947,200
Sub Saharan Africa	9,413,455,900

2.2.4 Health expenditure savings

An integrated biogas, sanitation, and latrine program generates health benefits by reducing acute lower respiratory infection (ALRI) and diarrheal diseases through elimination of indoor air pollution and reduction in sanitation and hygiene water-related diseases. Hence by including only these two diseases, the study is conservative given the larger number of other proven health impacts of unsafe sanitation and exposure to indoor air pollution (Prüss-Ustün et al., 2004; Fishman et al., 2004; Bruce et al., 2006). Reductions in health-related expenditures represent actual financial savings for affected households.

Financial benefits

The household financial savings of health expenditures is related to the treatment-seeking behavior of the household and tariffs for health service use for the two major diseases included in this study: ALRI related to exposure to indoor air pollution and diarrheal disease related to unsafe sanitation facilities and poor hygiene practices. Both of these diseases disproportionately affect the poor, who endure high levels of cooking-related indoor air pollution and lack access to sanitation. For example, from a recent Living Conditions Survey in Rwanda, respiratory infection represents 18.2% of all illnesses, while diarrheal disease represents 1.3% and intestinal parasites 21.4%. In Ethiopia, acute respiratory infection is reported to account for 13.5 deaths per 1,000 deaths and diarrhea seven deaths per 1,000 deaths.

Disease incidence depends on age group as well as coverage status (i.e., fuel use and stove type for ALRI, and sanitation coverage for diarrheal disease). Demographic data for Sub-Saharan Africa based on U.N. Statistics from Hutton et al. (2006) shows the population distribution by age as follows: ages 0–1 years (4.5%), ages 1–4 years (11.5%), ages 5–14 years (26%), and ages

15 and older (58%). The annual incidence of diarrhea for these age groups is shown in Table 21. These estimates, which are used in the present analysis, were deemed more reliable than estimates compiled from DHS, which collect data on "diarrheal incidence in past 3 weeks" due to the complex task of converting this variable to annual incidence rates by age group.

Table 21: Annual incidence of diarrhea for households with unimproved water, sanitation and hygiene, by age group and African sub-region

WHO sub-region	Age group				
	0-1	1-4	5-14	15-59	60+
AFR-D	13.0	4.9	1.17	0.39	0.39
AFR-E	12.8	4.8	1.16	0.38	0.38
Average SSA	12.9	4.85	1.165	0.385	0.385

Source: WHO (unpublished data) on incidence which was used in the global cost-benefit study (Hutton et al 2004).

The risk reduction from latrine and hygiene interventions is available from international reviews of evidence. Fewtrell et al (2005) find hygiene interventions (excluding poor quality studies) have a relative risk of diarrheal disease of 0.55 or, in other words, a 45% reduction. Interestingly, multiple interventions (e.g., water, sanitation, and hygiene) are no more effective than the most effective single interventions individually (such as a solo hygiene or sanitation program); hence, a proportional reduction in diarrheal disease of 45% reduction is assumed following the combined sanitation and hygiene interventions.

The financial cost savings are related to the reduction in diarrheal episodes of people who seek treatment. The Living Condition Survey from Rwanda reports 19.6% of the population reporting illness in the past 2 weeks with 6.5% seeking care from a medical practitioner. In other words, an average rate for seeking care for any disease of 33%, which means that roughly one-third of people who are ill seek treatment. Some cases of people seeking treatment will be severe enough to require hospitalization. For this study, it is assumed that 10% of diarrheal disease cases will result in inpatient admission (based on 8.2%, unpublished WHO data).

The annual number of cases of ALRI per child is estimated from global data compiled by WHO. WHO estimates an annual incidence of ALRI for those under five-year-old for its two subregions in Sub-Saharan Africa—15.03 million in AFR-D and 14.07 million in AFR-E. According to the U.N. Population Division, the total population size for this age group is 125 million (combined AFR-D and AFR-E). This gives an annual incidence in Sub-Saharan Africa attributable to indoor air pollution of 0.23 cases per year per child under five years[10]. The proportion of ALRI episodes seeking treatment is taken from the global cost-benefit analysis of reducing exposure to indoor air pollution (Hutton et al, 2006) at 55.7% for AFR-E, 33.0% for AFR-D, and 44.4% for Sub-Saharan Africa. It is assumed that 20% of those seeking care for ALRI will be severe enough to require hospitalization.

The cost per consultation varies by country, depending on actual costs of services and the tariff policy of the country. In Uganda, treatment for infants and young children is now free. In

[10] Estimated incidence as 29.1/124959 = 0.232876.

Rwanda, the cost is US$3.6 per consultation. In rural areas, 44.5% of the population belongs to some kind of insurance (41% community insurance scheme and 3.5% other). Those with coverage pay 10% of the consultation cost and the other 90% is covered by insurance; hence, 65.4% of population will pay the full consultation cost. For inpatient care, 3.5 days per inpatient are assumed for diarrhea and 4.9 days are assumed for ALRI (Tan-Torres et al 2005, BMJ).

In addition to health care tariffs, patients will incur other nonhealth financial costs for both outpatient and inpatient care. Studies for other disease treatment–seeking (e.g., malaria in Tanzania) show that outpatient visit costs roughly average US$0.30 a visit. For inpatient care, the assumption is US$0.50 per inpatient admission (Adam et al and Tediosi et al 2006). The total financial benefits of health expenditure savings ranges are shown in Table 22.

Economic benefits

For an estimation of economic costs, different unit costs are applied, based on the full costs of the services. Unit costs of health services are taken from a chapter on unit health service costs prepared for the Disease Control Priorities Project (Mulligan et al, 2005), and additional ALRI costs taken from the global cost-benefit analysis study (Hutton et al., 2006). The commonly seen diarrheal disease is treated with low cost oral dehydration supplements (about US$0.02 per packet). The time taken to access services is also included in economic costs, with an assumption of one day required for seeking outpatient care and three days required for taking, fetching, and staying by the hospitalized child. The total economic benefits of health expenditure savings are shown in Table 22.

Table 22: Financial and economic benefits of Health expenditure savings (US$)

Country/Region	Financial Benefits	Economic Benefits
Uganda	375,338	13,607,606
Rwanda	2,168,881	8,424,030
Ethiopia	1,309,058	4,965,001
Sub-Saharan Africa	343,859,746	1,119,372,370

2.2.5 Health-related productivity

As well as out-of-pocket treatment costs, financial costs of morbidity conditions (illness) include time spent away from income-earning activities. Only diarrheal disease is included in the financial estimate, because there are assumed to be no financial implications for the 0–5 age group in the case of ALRI. Economic costs involve time lost from productive activities, such as agricultural production.

Financial benefits

A high proportion of the workforce in rural areas of the three countries and Sub-Saharan Africa are involved in subsistence agriculture or other activities that do not involve direct financial remuneration. In Uganda and Rwanda, 10% of the rural working adult population are reported to be involved in salaried work and, therefore, this proportion are assumed to be losing direct financial income from being sick. The length of incapacitation for diarrheal disease varies by age group and is assumed to be two days for the adult population. The daily value is based on the unskilled rural wage rates in each country used for the study as previously described. The total financial benefits of health-related productivity associated with averted cases of diarrheal disease are shown in Table 23.

Economic benefits

Economic costs are related to the lost time from all productive activities. For the income-earning adult population, the financial costs are included as before. For the affected population of non-income-earning adults and children, the value of time is approximated by the GDP per capita, which is less than the rural (agricultural) wage rate. The days of incapacity due to diarrhea are assumed to be five days for 0–1 year olds, four days for 1–4 year olds, three days for 5–14 year olds, and two days for 15 years and older. For ALRI, the nonsevere form of the disease takes five days for recovery (if treated) and 10 days if not. For severe ALRI, the time of incapacity is 10 days for treated cases and 20 days for untreated cases. In this study, all cases are conservatively assumed to be nonsevere. For diarrhea, no distinction is made between treated and untreated. The total economic benefits of health-related productivity associated with averted cases of diarrheal disease and ALRI are shown in Table 23.

Table 23: Total Financial and Economic benefits of health-related productivity (US$)

Country/Region	Financial Benefits	Economic Benefits
Uganda	82,554	773,071
Rwanda	59,508	557,271
Ethiopia	43,344	348,857
SSA	7,004,340	64,840,454

2.2.6 Value of saved lives

Deaths related to diarrheal disease and ALRI result in both financial and economic costs. An integrated biogas, sanitation, and hygiene program will reduce illness and deaths associated with diarrheal disease and ALRI and result in financial and economic benefits for households and society as a whole.

Financial benefits

The financial cost of saved lives is related primarily to the funeral costs of the deceased individual. The number of deaths is calculated from the incidence and case fatality rate (CFR). Case fatality for diarrhea is from unpublished WHO data used in Hutton et al. (2007) (see Appendix Table A.3). Case fatality for ALRI is based on the number of deaths compared with the annual incidence for ALRI in Africa (AFR-E CFR = 0.0146837; AFR-D CFR = 0.0136494;

SSA CFR = 0.0141665).[11] For adult deaths, there would be some income losses, but this is excluded due to the small proportion of income-earning adults and the low case fatality rate for older age groups. In Uganda the funeral cost is assumed to be US$55. In the other countries, in the absence of data, the funeral cost is assumed to be higher at US$75. Table 24 shows the total financial benefits of lives saved due to an integrated biogas, sanitation, and hygiene intervention.

Economic benefits

The economic costs of premature death are estimated by applying a value-per-death methodology. This is commonly done using the "value of a statistical life" (VOSL), using observations of risky behavior; however, VOSL studies from developing countries are rare. Reviews from North America and Western European countries have shown the VOSL to lie somewhere between US$1 million and US$5 million, with a relatively conservative mean estimate of US$2 million. This value is extrapolated to developing countries based on differences in economic levels, using two methods: the purchasing power parity (PPP) method and the market exchange rate. The PPP method is used in the base case, because it better reflects the economic value of premature death at local purchasing power. Table 25 shows the total economic benefits of lives saved due to an integrated biogas, sanitation, and hygiene intervention.

Table 24: VOSL adjustment based on two different methods, at VOSL in United States of US$2 million

Country	GDP (2005)		Equivalent VOSL	
	In I$, valued at PPP	In US$, valued at official exchange rate	Using PPP to adjust	Using market values to adjust
Ethiopia	1,000	160	47,676	7,316
Rwanda	1,320	230	62,932	10,517
Uganda	1,500	280	71,514	12,803
SSA	1,981	745	94,446	34,065
USA	41,950	43,740	-	-

Table 25: Total Financial and Economic benefits of value of saved lives (US$)

Country/Region	Financial Benefits	Economic Benefits
Uganda	118,493	154,189,538
Rwanda	100,988	84,839,632
Ethiopia	340,767	52,153,924
SSA	12,962,368	16,336,212,900

[11] AFR-E–Incidence 14,078,781 deaths 206,729 = implied CFR = 0.0146837
AFR-D–Incidence 15,031,813 deaths 205,176 = implied CFR = 0.0136494
SSA = average of AFR-D and AFR-E = 0.0141665

2.2.7 Lighting benefits

The financial benefit to households associated with biogas lighting is due to reduction in kerosene expenditures, which are assumed to decline by 75%. Data for annual kerosene consumption and prices were collected during field surveys carried out for the country feasibility studies. Field surveys indicate annual kerosene consumption per household as follows: Uganda (60 L), Rwanda (60 L), and Ethiopia (18 L). For Sub-Saharan Africa, kerosene consumption is estimated using the average of these three countries (46 L). Prices of kerosene per liter are US$0.9 in Uganda and Rwanda and US$0.68 in Ethiopia, resulting in an average price used for Sub-Saharan Africa of US$0.8 per liter. Assuming that 50% of households with biogas plants use them for lighting purposes as well as for cooking, the annual household-level financial savings from reduced kerosene expenditures for lighting will be US$8 in Uganda and Rwanda, US$3 in Ethiopia, and US$7 in Sub-Saharan Africa. The total financial benefits of lighting are shown in Table 26.

Economic benefits

The economic benefits of lighting include the financial benefits plus the benefits associated with increased study time in the evening for the students. On average, it is estimated that students will get an extra 1.5 hours of evening study time after installation of the biogas plant. The value of time assigned to education benefits is 20% of the unskilled rural wage rate used throughout the analysis. Table 26 shows the total economic benefits associated with using biogas for lighting.

Table 26: Economic and Financial value of lighting benefits (US$)

Country/Region	Financial Benefits	Economic Benefits
Uganda	8,323,699	9,399,017
Rwanda	6,075,000	6,850,125
Ethiopia	1,323,000	1,734,071
Sub Saharan Africa	690,966,000	781,016,566

2.2.8 Global environmental benefits—GHG Emissions

Biogas plants also help reduce greenhouse gas (GHG) emissions. Because a single household can not develop a Clean Development Mechanism (CDM) program under the Kyoto Protocol for an individual plant, the benefits from CDM revenue will not be realized by the households and thus its reduction in GHG emissions is considered an economic benefit and not financial. It is envisioned that the national program for each country will develop qualifying CDM projects for all plants constructed under the program.

Economic Benefits

The global environmental value of GHG emissions reduction by a biogas plant is calculated as the product of the total reduction in emissions and the market price of carbon reduction. An average biogas plant realizes a 5t CO2 GHG emission per year.[12] A biogas plant is expected to continue reducing GHG emissions for its entire expected lifespan of 20 years. As biogas is a proven technology in many Asian countries, 95% of the installed plants are assumed to be functional for the entire 20-year life span of the plant. Emission reductions are valued at US$10 per ton CO2e. Table 27 shows the economic value of GHG emissions.

Table 27: Total economic benefits of GHG emission reductions (US$)

Country/Region	Economic Benefits
Uganda	17,880,000
Rwanda	13,367,500
Ethiopia	8,855,000
Sub Saharan Africa	2,086,268,500

2.2.9 Local environmental benefits

In addition to global environmental benefits, biogas interventions also have a direct impact on the local environment. Local environmental benefits occur as part of a switch away from biomass to cleaner fuels or when improved and more fuel-efficient stoves lead to less consumption. Essentially, this results in fewer trees being cut down in an unsustainable fashion (being used either for firewood or charcoal). The local effects of trees being cut down are soil erosion, desertification, and, in hilly areas, landslides. The costs of these are many, but have a high level of uncertainty and are difficult to value in economic terms, because cost varies depending on the human interaction with the land (e.g., population density, use of land for farming) and geographical factors (e.g., steepness and presence of rivers); therefore, an alternative way of valuing the economic cost is the replacement cost to avert the possible future effects of deforestation (avertive expenditure). This essentially means that the replacement cost is the same for trees cut down in a renewable or nonrenewable fashion.

The replacement cost is the cost of replanting trees in a renewable fashion, which is made up of the labor cost plus the tree sapling cost, adjusted by a wastage factor (defined as the percentage of planted saplings that do not mature). The number of kilograms of wood used annually for domestic cooking purposes is available from the model (average consumption per household multiplied by the number of households using firewood). This figure is transformed into the number of tree-equivalents by dividing the kilograms of wood consumption by the average weight of firewood per tree, which is estimated to be 0.167 m3, or 100 kg (Carneiro de Miranda, 1997). A search undertaken on the Internet and of environmental economics and forestry journals revealed very little information. Carneiro de Miranda (1997) estimated the cost to reforest one tree in Brazil at US$0.25, including seedling, technical assistance, fertilizer, wire, pesticide, and administration (Carneiro de Miranda, 1997). This was adjusted to 2005 costs using a 10.2% average inflation rate for Brazil, giving US$0.60 (World Bank statistics). Krause and Koomey (1989) estimate the cost of US$1.33 per tree established in the ”Third World” (based on a cost of US$0.80 per tree planted with 60% survival probability). An average of the two studies yields a

[12] Based on the Biogas CDM project developed in Nepal, 2006.

value of US$0.965/tree or US$0.00965/kg, which is assumed to be the local environmental value of reduced charcoal and firewood usage. The total local environmental benefits are shown in Table 28.

Table 28: Local environmental benefits (US$)

Country/Region	Economic Benefits
Uganda	3,342,000
Rwanda	1,971,099
Ethiopia	2,122,200
Sub Saharan Africa	304,616,867

2. 2.10 Uncertainties in impacts

Certain uncertainties in impacts may arise due to the following:

- Impracticality of utilizing the time saved for income-generating activities, due to lack of work opportunities in actual rural scenarios. In other words, there is no certainty that the valuation of the time saved is practical, because in reality, the time saved is more often utilized in such activities as family health care, adult literacy, etc.
- The value of market value of fertilizer reflects local conditions, such as distance to market.
- For VOSL, it is uncertain how a particular lost life could have been used productively.

2.3 Sensitivity Analysis Scenarios

A range of sensitivity analyses were conducted to assess how changes in key variables might influence financial and economic costs and benefits from the base case scenario, including variables related to the following:

- Program size
- Biogas plant costs
- Latrine costs and adoption rates
- Fuel savings
- Latrine access
- Fertilizer values
- Health expenditure
- Health-related productivity
- Value of saved lives
- Lighting savings
- Time savings.
- Environmental benefits
- Discount rate.

Table 29 provides details on sensitivity, including values for valuables under the base case, conservative and optimistic scenarios.

Table 29: Variables included in the sensitivity analysis and their alternative values

Sensitivity analysis	Variable	Conservative	Base case	Optimistic
SENSITIVITY ANALYSIS 1	Program size (% of base case)	75%	100%	125%
	Uganda	15,000	20,000	25,000
	Rwanda	11,250	15,000	18,750
	Ethiopia	7,500	10,000	12,500
	SSA	1,502,100	2,002,800	2,503,500
Biogas plants & latrines				
SENSITIVITY ANALYSIS 2	Biogas plant costs	125%	100%	75%
SENSITIVITY ANALYSIS 3	a) Percent of households installing improved latrine			
	Uganda	30%	50%	70%
	Rwanda	30%	50%	70%
	Ethiopia	50%	75%	90%
	SSA	30%	50%	70%
	b) No latrine	0%		
SENSITIVITY ANALYSIS 4	a) Latrine costs	150%	100%	50%
	Uganda	$426	$284	$142
	Rwanda	$383	$255	$128
	Ethiopia	$300	$200	$100
	SSA	$300	$200	$100
	b) Latrine Subsidy			30%
Fuel saving benefits				
SENSITIVITY ANALYSIS 5	a) Level of purchased fuel	15%	25%	40%
	b) Reduction in purchased fuel (Charcoal)	75%	90%	95%
	c) Reduction in purchased fuel (Firewood)	56%	75%	94%
SENSITIVITY ANALYSIS 6	Fuel prices			
	Uganda			
	Charcoal	$0.11	$0.14	$0.18
	Firewood	$0.05	$0.06	$0.08
	Rwanda			
	Charcoal	$0.20	$0.27	$0.34
	Firewood	$0.05	$0.07	$0.09
	Ethiopia			
	Charcoal	$0.14	$0.18	$0.23
	Firewood	$0.06	$0.08	$0.10
	SSA			
	Charcoal	$0.20	$0.27	$0.34
	Firewood	$0.03	$0.04	$0.05

Sensitivity analysis	Variable	Conservative	Base case	Optimistic
SENSITIVITY ANALYSIS 7	% Time savings uses for income earning	15%	20%	25%
Fertilizer use benefits				
SENSITIVITY ANALYSIS 8	Value of slurry per plant ea. yr	75%	100%	125%
	Uganda	347	463	578
	Rwanda	260	347	434
	Ethiopia	140	187	234
	SSA	220	294	367
Health benefits				
Health expenditure savings				
SENSITIVITY ANALYSIS 9	% risk reduction of diarrheal disease from latrine / hygiene	30%	45%	60%
	% risk reduction of ALRI	50%	100%	
Health related productivity benefit				
SENSITIVITY ANALYSIS 10	Length of illness			
	Diarrheal disease	1	2	3
	ALRI (treated)	3	5	7
Value of lives saved (VOSL)				
SENSITIVITY ANALYSIS 11		75%	100%	125%
	Uganda	$53,636	$71,514	$89,393
	Rwanda	$47,199	$62,932	$78,665
	Ethiopia	$35,757	$47,676	$59,595
	SSA	$70,835	$94,446	$118,058
Value of lighting benefits				
SENSITIVITY ANALYSIS 12	% households using biogas for lighting	38%	50%	63%
	% reduction in fuel for lighting	56%	75%	94%
Time savings				
SENSITIVITY ANALYSIS 13	Value of time	75% of the rural wage rate for unskilled labor ($/hr)	100% of the rural wage rate for unskilled labor ($/hr)	125% of the rural wage rate for unskilled labor $/hr)
	Uganda	$0.1626	$0.2168	$0.2710
	Rwanda	$0.1875	$0.2500	$0.3125
	Ethiopia	$0.1394	$0.1858	$0.2323
	SSA	$0.1631	$0.2175	$0.2719
Environmental benefits				
SENSITIVITY ANALYSIS 14	Price of ER	$7	$10	$13
General				
SENSITIVITY ANALYSIS 15	Discount rate	5%	3%	1%

3.0 Results

3.1 Financial analysis

3.1.1. Discussion of base case and sensitivity analysis

The financial analysis provides information on financial attractiveness of an integrated biogas, latrine, and hygiene program from the perspective of the consumer. The base case scenario assumes installation of improved pour-flush latrines among 50% of households in Uganda and Rwanda, 75% in Ethiopia, and 50% for Sub-Saharan Africa. From the household's perspective, purchase of a biogas plant represents a significant household investment, and the level of investment grows when a pour-flush latrine is included. Investment in biogas does not directly generate cash income; it saves on household expenditures and indirectly generates income through productive use of time savings.

Table 30 provides benefit-cost ratios (BCRs) and financial internal rates of return (FIRRs) for the base case analysis for country programs and for the Sub-Saharan Africa initiative as a whole. The BCRs range from a low of 1.22 for Sub-Saharan Africa to 1.35 for Ethiopia, and FIRRs range from 7.5% in Sub-Saharan Africa to 10.3% in Ethiopia. The higher returns to Ethiopia and Rwanda appear due to lower latrine costs in Ethiopia, a higher biogas subsidy in Rwanda (US$300 verses ~US$200 elsewhere), and differences in health expenditures savings.[13] For the base case, the BCRs and FIRRs reflect relatively high capital investment costs, particularly associated with unsubsidized latrines (which are estimated to cost from US$180–US$230 per household) in relation to fuel and other expenditure savings.

Table 30: Summary of financial analysis: benefit-cost ratio and FIRRs

Country/Region	Benefit-Cost Ratio	FIRR
Uganda	1.25	8%
Rwanda	1.32	9.5%
Ethiopia	1.35	10.3%
Sub-Saharan Africa	1.22	7.5%

The results for the country programs and for the sub-Saharan Africa initiative as a whole are discussed below.

Uganda. Under the base case scenario for Uganda with a US$200 subsidy on a $8m^3$ biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the BCR is 1.25 and the FIRR 8%. Table 31 provides a more detailed picture of the costs and benefits. On the cost side, the largest financial cost is the biogas plant investment and repair (63%) followed by latrine capital costs (30%) and hygiene materials cost (7%). On the benefits side, the largest financial benefit is fuel cost savings (58%) followed by lighting benefits (25%) and latrine access savings (16%). The value of health expenditure savings is small (~1% of total benefits) relative to other countries, because free health care is

[13] Ethiopia does not provide free health care provided by the government thus, patients pay the full costs of visiting, whereas in Uganda treatment for infants and children is now free from government clinics.

provided by the government to children, who are particularly affected by diarrheal disease and acute lower respiratory illness (ALRI). Because the financial value of lighting benefits is based on a reduction in kerosene expenditures, the total net present value of cooking and lighting fuel expenditure savings associated with biogas is approximately US$19.7 million, which exceeds the biogas capital and O&M costs of US$12.2 million by US$7.5 million.

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. For the financial analysis, sensitivity analysis was conducted to assess the importance of a number of key variables, including biogas plant cost, latrine cost and program, fuel savings, latrine access, lighting savings, time savings, and the discount rate. As described in section 2.3, both conservative and optimistic scenarios were assessed. Figures 2 and 3 show the benefit-cost ratios and FIRRs for the sensitivity analysis. Of all the scenarios evaluated, the latrine and biogas plant costs have the greatest effect on the results.

Under the optimistic scenario, a reduction in the cost of the biogas plant by 25% boosts the BCR from 1.25 to 1.57 and the FIRR from 8% to 15.5%. A similar effect is observed for the latrine cost—a 25% reduction in cost increases the BCR from 1.25 to 1.47 and the FIRR from 8% to 11.5%. When the number of households who install latrines decreases, from 50% of all households receiving a biogas plant to 30%, the BCR increases from 1.25 to 1.42 and FIRR increases to 10.7. This suggests that it is more the cost than the number of latrines installed that influences financial performance. Given that the cost of latrines is quite high in the base case, it seems reasonable to assume that the pessimistic scenario is quite unlikely. Indeed, even the base case cost for latrines seems relatively high. Due to the high cost of latrines, an elimination of the latrine program was evaluated. Under the scenario with no latrines, the BCR increases to 1.77 and FIRR to 15.5%.

The only other variable that appears to influence the outcome of the financial analysis for Uganda significantly is the amount of purchased fuel wood. When the number of households purchasing firewood increases from 25% to 40%, the FIRR increases from 8% to 12.5%. However, a similar drop in purchases of firewood from 25% to 10% reduces the FIRR to 5%. Similar, but less pronounced, effects are observed when the price of purchased fuel and amount purchased per household increases.

The results presented are for an "average." The BCR and FIRR faced by a particular household will depend, among other things, on the choice to install a latrine and the amount of purchased fuel used and prices. With these caveats in mind, the results suggest that an integrated biogas and sanitation intervention should be generally financially attractive from the household perspective unless the costs of either the biogas plant and latrines increase significantly or the price of firewood drops significantly. However, the choice of whether a household will invest or not, depends on the opportunity cost of capital and how they compare with anticipated FIRRs.

Table 31: Uganda: summary of financial and economic analysis (net present values)

Type of Cost/Benefit	Uganda Financial Costs And Benefits	Economic Costs and Benefits
COSTS		
Biogas	12,210,105	35,420,104
Latrine	5,762,600	6,447,979
Hygiene	1,340,475	5,372,263
Total costs	**19,313,181**	**47,240,347**
BENEFITS		
Fuel cost savings	13,923,225	41,054,252
Latrine access savings	3,977,115	39,771,150
Fertilizer use benefits		103,381,591
Health expenditure savings	262,047	9,500,344
Health-related productivity	57,637	539,897
Value of saved lives	82,728	107,649,628
Lighting benefits	5,811,310	6,562,058
GHG emission reductions		12,262,394
Local environmental benefits		2,333,265
Total benefits	**24,114,062**	**323,054,580**
NPV of Net Returns	**4,800,881**	**275,814,233**
BCR	**1.25**	**6.84**
Internal rate of return (IRR)	**8%**	**166%**
Discount rate	3.0%	
Length of program	5 yrs	
No. of biogas plants installed	20,000	
No. of latrines installed (50%)	10,000	

Figure 2: Uganda sensitivity analysis for financial returns: benefit-cost ratios

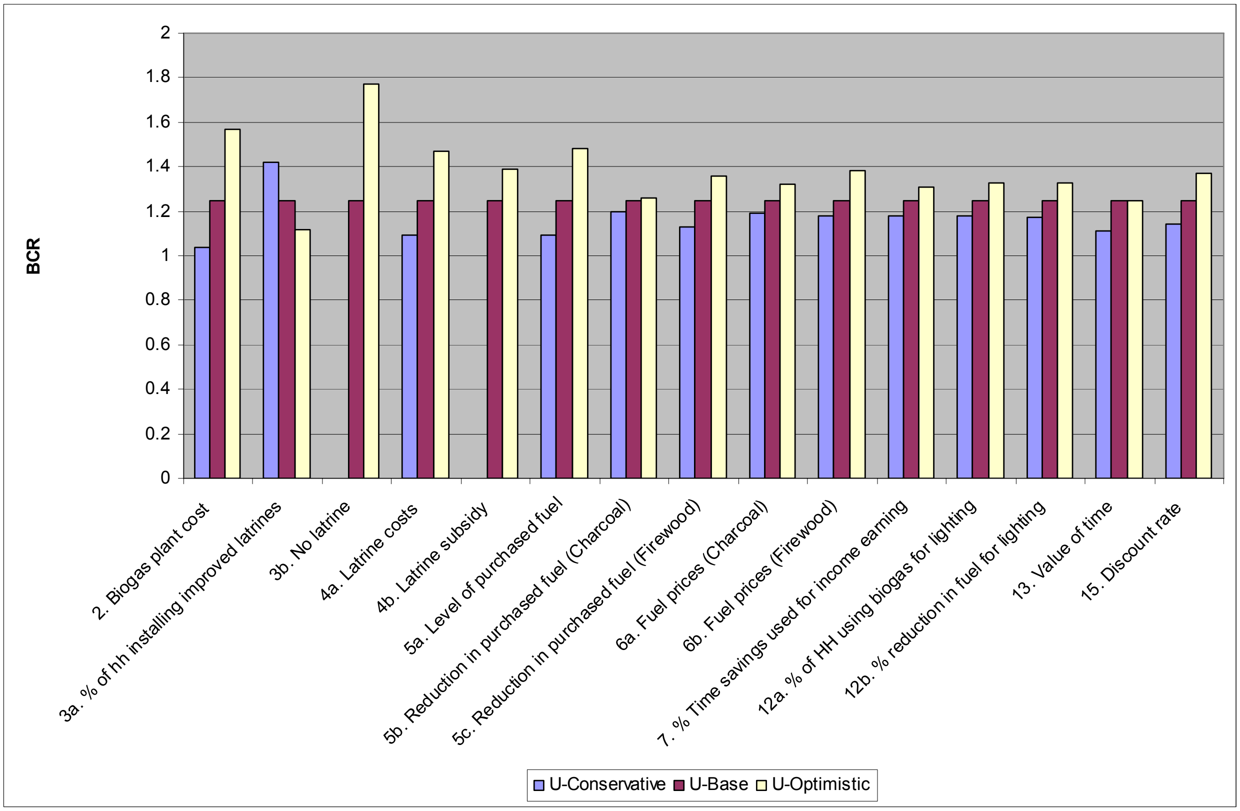
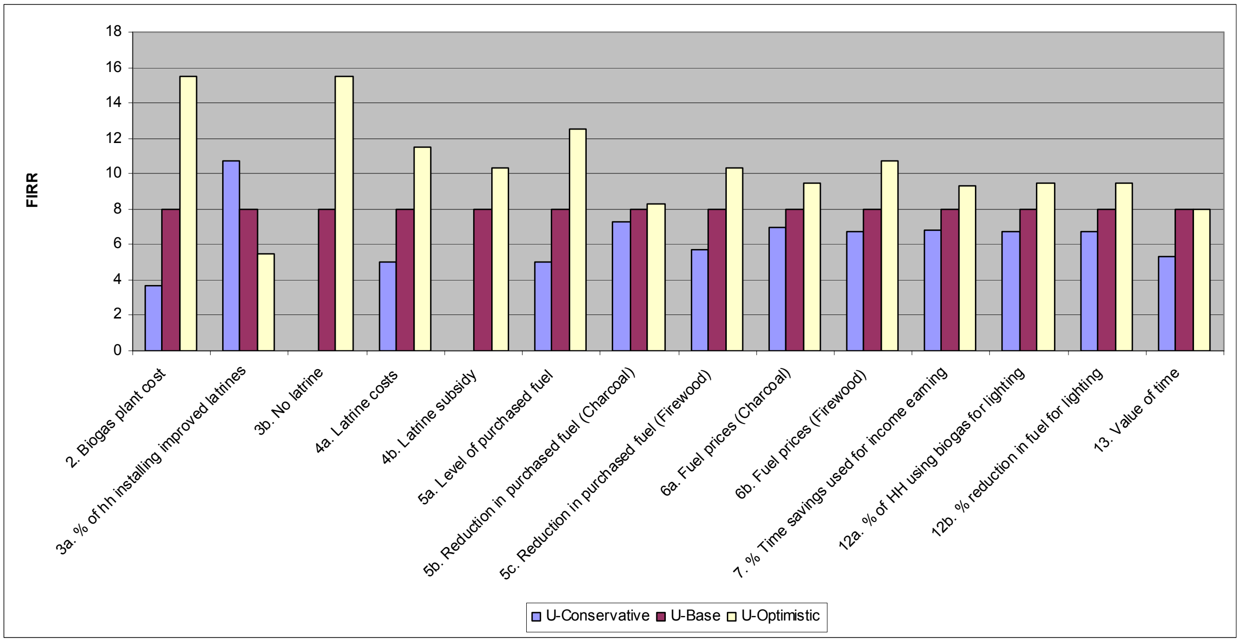


Figure 3: Uganda sensitivity analysis for financial returns: FIRRs



Rwanda. Under the base case scenario for Rwanda with a US$300 subsidy on a 6m3 biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the BCR is 1.32 and the FIRR is 9.5%. Table 32 provides a detailed breakdown of financial costs and benefits. Of the total costs, Biogas plant investment and repair constitute 65%, followed by latrine capital costs (28%) and the cost of hygiene materials (7%). On the benefits side, the fuel and lighting cost savings make up 73% of total benefits, followed by latrine access (19%) and health expenditure savings (8%).

Table 32: Rwanda: summary of financial and economic analysis (net present values)

	Rwanda	
Type of Cost/Benefit	Financial Costs and Benefits	Economic Costs and Benefits
COSTS		
Biogas	9,169,851	27,712,940
Latrine	3,882,595	4,347,830
Hygiene	1,005,867	4,488,845
Total costs	**14,058,313**	**36,549,614**
BENEFITS		
Fuel cost savings	9,269,179	35,812,774
Latrine access savings	3,441,952	28,682,932
Fertilizer use benefits		58,181,681
Health expenditure savings	1,515,004	5,884,344
Health-related productivity	41,567	389,385
Value of saved lives	70,542	59,262,086
Lighting benefits	4,243,502	4,784,942
GHG emission reductions		9,167,251
Local environmental benefits		1,376,850
Total Benefits	**18,581,746**	**203,542,244**
NPV of Net Returns	**4,523,433**	**166,992,630**
BCR	**1.32**	**5.57**
Internal rate of return (IRR)	**9.5%**	**161**
Discount rate	3.0%	
Length of program	5 yrs	
No. of biogas plants installed	20,000	
No. of latrines installed (50%)	10,000	

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. For the financial analysis, the value of key variables related to biogas plant cost, latrine cost, fuel savings, latrine access, lighting savings, time savings, and the discount rate were evaluated. Figures 4 and 5 show the benefit-cost ratios and FIRRs for the sensitivity analysis. Of all the scenarios evaluated, the costs of the latrine and biogas plant and number of households installing latrines have the greatest effect on financial performance.

Under the optimistic scenario, a reduction in the cost of the biogas plant by 25% boosts the BCR from 1.32 to 1.73 and the FIRR from 9.5% to 20%. A similar effect is observed for the latrine cost: a 25% reduction in cost increases the BCR from 1.32 to 1.53 and the FIRR from 9.5% to 13%. As mentioned above, given that the cost of latrines is quite high in the base case, it seems reasonable to assume that the conservative scenario for latrines (25% cost increase) is quite unlikely. Under the scenario for no latrines, the FIRR increases from 9.5% to 15.5%.

Beyond the biogas plant and latrine, the variables having the most significant impact on financial performance relate to purchases of firewood, including number of households who purchase and prices paid. A reduction in purchased firewood-related variables (e.g. % of households who purchase or prices paid, reduces the FIRR from the base case 9.5% to between 7.5 and 8%.

As indicated above, the results of the analysis are for “average” households. These results suggest that the relative FIRRs will likely increase for households that only purchase firewood and decrease for those that collect. With these caveats in mind, the results suggest that unless the cost of the biogas plant or latrine increase significantly or purchased firewood amount and prices drop significantly, an integrated biogas and latrine program should be generally financial attractive to the household. The choice of whether a household actually invests will depend on their anticipated FIRR and perceived opportunity costs of capital, among other factors.

Figure 4: Rwanda sensitivity analysis for financial returns: benefit-cost ratios

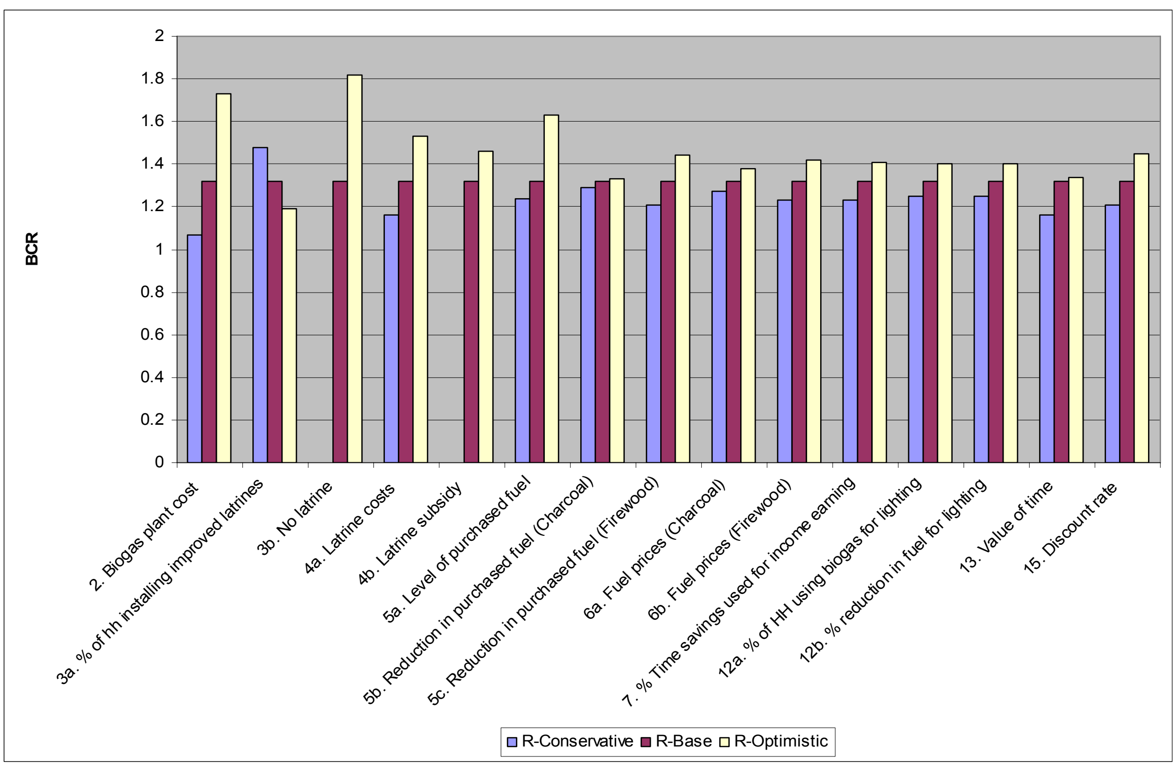
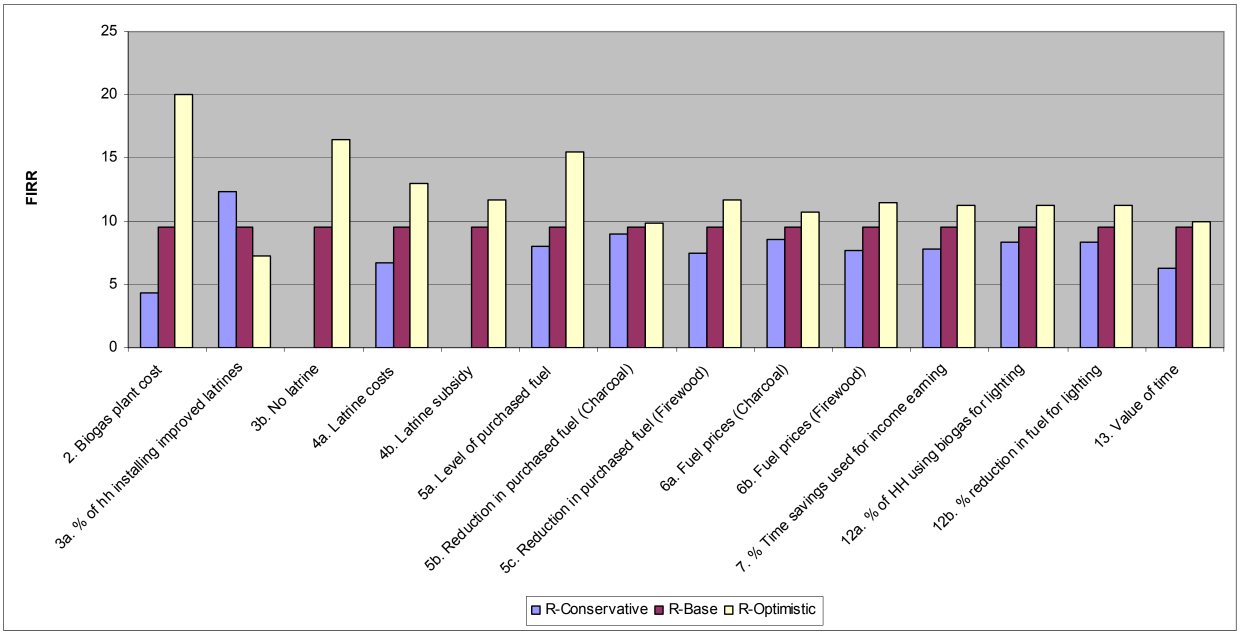


Figure 5: Rwanda sensitivity analysis for financial returns: FIRRs



Ethiopia. Under the base case scenario for Ethiopia with a US$185 subsidy on a $6m^3$ biogas plant, 75% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the BCR is 1.35 and the FIRR is 10.3%. A breakdown of financial costs and benefits is provided in Table 33. The composition of total costs is as follows: biogas plant investment and repair (62%), latrine investment (31%), and cost of hygiene materials (7%). As with the other countries, the largest share of financial benefits are due to fuel and lighting cost savings (72%), followed by latrine access savings (19%), health expenditure savings (7%), and value of lives saved (2%). The financial component of the value of lives saved (VOLS) benefit is the reduction in funeral-related expenses.

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. For the financial analysis, the value of key variables related to biogas plant cost, latrine cost, fuel savings, latrine access, lighting savings, time savings, and the discount rate were evaluated. Figures 6 and 7 show the benefit-cost ratios and FIRRs for the sensitivity analysis. Of all the scenarios evaluated, variables related to the latrine, purchased firewood, and biogas plant have the greatest effect on financial performance.

The greatest impact on financial performance is observed by eliminating the latrine program, which boosts the FIRR from 10.3% to 18.3%. A reduction in latrine costs or the introduction of a 30% latrine subsidy has a similar, yet more muted, effect on increasing the FIRR. Variables related to firewood purchases, especially the number of households that purchase firewood (e.g., scenario 5a., level of purchased fuel) have a significant impact on financial performance. For example, when the number of households purchasing firewood decreases from 25% to 15%, the FIRR drops from 10.3% to 4%. However, an increase in purchase of firewood from 25% to 40% increases the FIRR to 19.3%. Similar, but less pronounced, effects are observed when the price of purchased fuel and amount purchased per household increases. Regarding biogas plant costs, a reduction in the cost of the biogas plant by 25% boosts the BCR from 1.35 to 1.69 and the FIRR from 10.3% to 18.5%.

These results suggest that an integrated biogas and latrine program should generally be attractive from a household perspective; however, the choice of whether to invest will depend on their perceived FIRR and opportunity costs of capital.

Table 33: Ethiopia: financial and economic analysis (net present values)

Ethiopia Type of Cost/Benefit	Financial Costs and Benefits	Economic Costs and Benefits
COSTS		
Biogas	6,005,546	19,212,364
Latrine	3,060,029	3,434,033
Hygiene	664,121	2,415,126
Total costs	**9,729,697**	**25,061,523**
BENEFITS		
Fuel cost savings	8,503,672	21,573,249
Latrine access savings	2,533,575	21,422,404
Fertilizer use benefits		21,020,744
Health expenditure savings	924,079	3,485,067
Health-related productivity	30,597	244,985
Value of saved lives	240,552	36,608,239
Lighting benefits	933,921	1,217,191
GHG emission reductions		6,096,073
Local environmental benefits		1,489,629
Total benefits	**13,166,394**	**113,157,582**
NPV Returns	**3,436,698**	**88,096,059**
BCR	**1.35**	**4.52**
Internal rate of return (IRR)	**10.3%**	**78.0%**
Discount rate	3.0%	
Length of program	5	
No. of biogas plants installed	10,000	
No. of latrines installed (75%)	7,500	

Figure 6: Ethiopia sensitivity analysis for financial returns: benefit-cost ratios

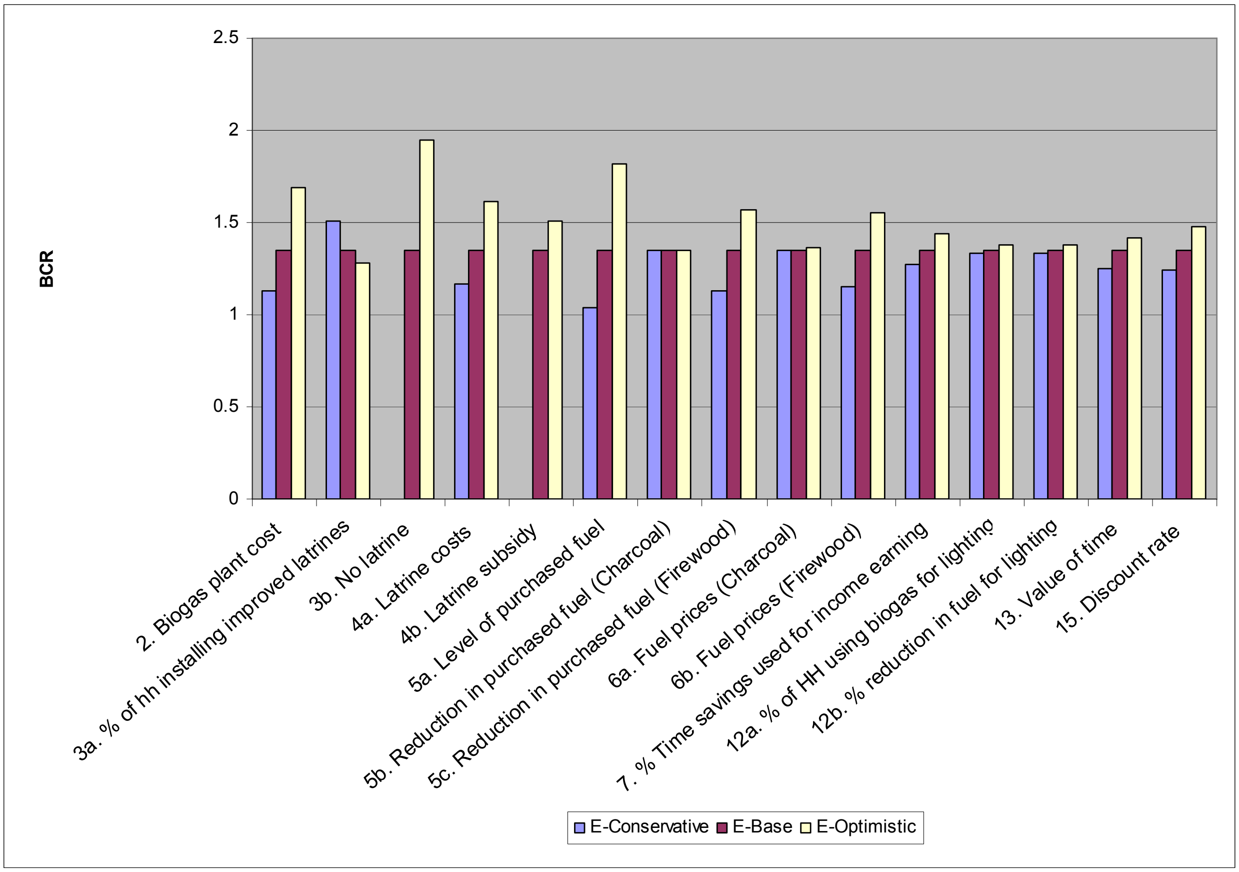
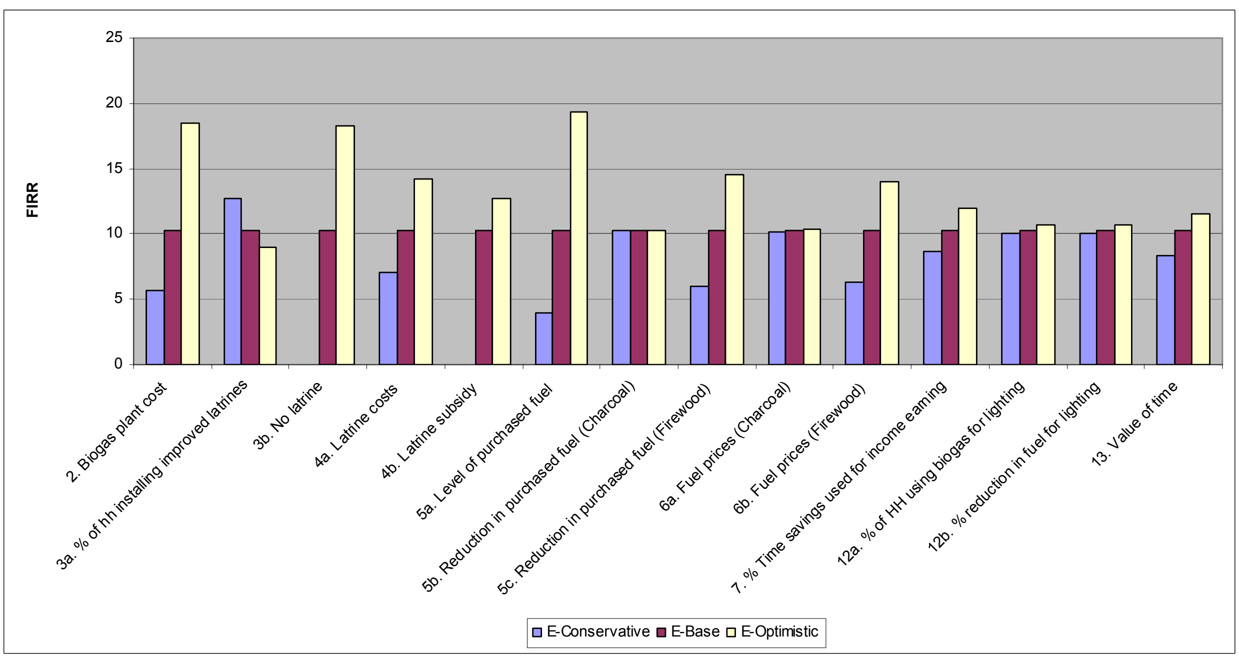


Figure 7: Ethiopia sensitivity analysis for financial returns: FIRRs



Sub-Saharan Africa. Under the base case scenario for the Sub-Saharan Africa program with a US$200 subsidy on a 6m^3 biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the BCR is 1.22 and the FIRR is 7.5%. Table 34 provides details on costs and benefits. On the cost side, the largest financial cost is the biogas plant investment and repair (65%) followed by latrine capital costs (28%) and hygiene materials cost (7%). On the benefits side, the largest financial benefit is fuel and lighting cost savings (70%) followed by latrine access savings (19%), health expenditure savings (11%), and value of lives saved (1%).

Table 34: Sub-Saharan Africa: financial and economic analysis (net present values)

Sub-Saharan Africa		
Type of Cost/Benefit	**Financial Costs and Benefits**	**Economic Costs and Benefits**
Biogas		
Latrine	1,039,673,125	2,991,633,328
Hygiene	376,546,958	422,569,364
Total costs	118,123,602	474,638,854
Biogas	**1,534,343,685**	**3,888,841,546**
BENEFITS		
Fuel cost savings	879,709,223	3,459,863,742
Latrine access savings	351,697,436	2,930,811,967
Fertilizer use benefits	0	5,783,316,453
Health expenditure savings	211,256,073	687,705,420
Health-related productivity	4,303,235	39,836,875
Value of saved lives	7,963,651	10,036,429,751
Lighting benefits	424,506,693	479,830,788
GHG emission reductions	0	1,210,800,231
Local environmental benefits	0	187,146,544
Total Benefits	**1,879,436,311**	**24,815,741,771**
NPV of Net Returns	**345,092,626**	**20,926,900,225**
BCR	**1.22**	**6.38**
Internal rate of return (IRR)	**7.5%**	**178%**
Discount rate	3.0%	
Length of program	15 years	
No. of biogas plants installed	2,002,800	
No. of latrines installed (60%)	1,201,680	

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. For the financial analysis, the value of key variables related to biogas plant cost, latrine cost, fuel savings, latrine access, lighting savings, time savings and the discount rate were evaluated. Figures 8 and 9 show the benefit-cost ratios and FIRRs for the sensitivity analysis. Of all the scenarios evaluated, the costs of the biogas plant, the latrine, and level of purchased fuel wood have the greatest effect on the results.

Under the optimistic scenario, a reduction in the cost of the biogas plant by 25% boosts the BCR from 1.22 to 1.57 and the FIRR from 7.5%% to 15.5%. However, a similar increase in cost has the opposite effect, pushing the FIRR to 3% when biogas plant costs are increased by 25%. Latrine costs have a similar, yet less pronounced impact on financial performance, as changes in the biogas plant. A 25% reduction in latrine cost increases the BCR from 1.22 to 1.40 and the FIRR from 7.5% to 10.3%. A latrine subsidy of 30% increases the base case FIRR from 7.5% to 9.3%.

When the latrine program is eliminated, the FIRR increases from 7.5% to 13%. The importance and costs of purchased fuel also have a significant impact on results in the sensitivity analysis. For example, a 25% increase in firewood prices raises the base case FIRR from 7.5% to 9%, whereas a 25% decline in prices reduces the FIRR to 6%.

These results suggest that an integrated biogas, latrine, and hygiene program should be generally attractive to rural households. However, given the pronounced impact of the cost of the biogas plant and latrine, careful evaluation of these costs are necessary to ensure financial attractiveness of the performance of the program. Ultimately, the willingness of a household to purchase a biogas plant and connecting latrine will depend, in part, on their perceived FIRRs and the opportunity cost of capital.

Figure 8: Sub-Saharan Africa sensitivity analysis for financial returns: benefit-cost ratios

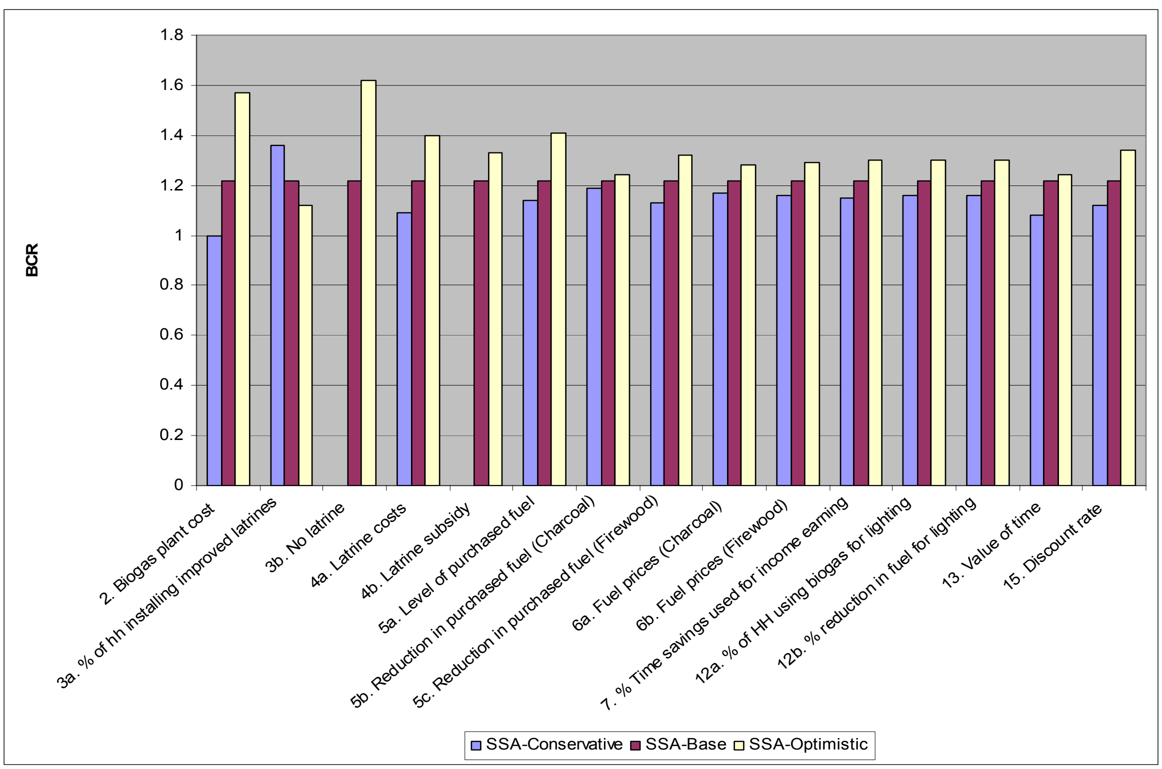
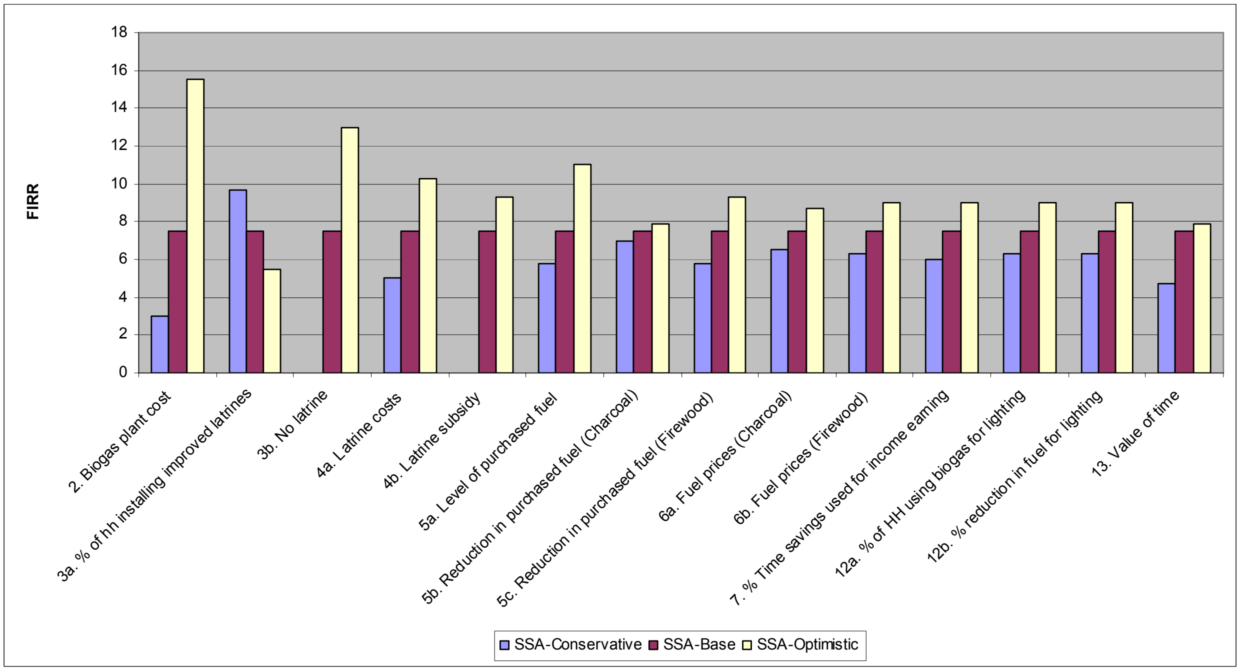


Figure 9: Sub-Saharan Africa sensitivity analysis for financial returns: FIRRs



3.2 Economic Analysis

The economic analysis captures the full costs and benefits of an integrated biogas, sanitation, and hygiene program to society. From the cost perspective, the economic costs include the full costs of implementing an integrated biogas program at the household as well as national and programmatic levels. From the benefits perspective, the economic benefits include the full range of cash and noncash benefits to households and society-at-large associated with the program. In all, nine types of benefits are valued, ranging from fuel cost savings to health-related impacts to environmental impacts.

3.2.1. Discussion of the Base case and sensitivity analysis

Table 35 provides benefit-cost ratios (BCRs) and economic internal rates of return (EIRRs) for the base case analysis for country programs and for the Sub-Saharan Africa initiative as a whole. The BCRs range from 4.52 in Ethiopia to 6.84 in Uganda, and EIRRs range from 78% in Ethiopia to 178% in Sub-Saharan Africa. The solid economic performance, relative to financial performance, reflects the nature of the intervention; an integrated biogas and latrine program involves significant capital investment and generates expenditure savings (rather than income), while yielding a wide range of economic (rather than financial) benefits such as improved health, increased availability of high quality fertilizers, time savings due to the reduced drudgery associated with fuel collection, and environmental benefits.

Table 35: Summary of Economic Analysis: Benefit-cost ratios and EIRRs

Country/Region	Benefit Cost Ratio	EIRR
Uganda	6.84	166%
Rwanda	5.57	161%
Ethiopia	4.52	78%
Sub Saharan Africa	6.38	178%

For the economic analysis, a wider range of sensitivity was conducted to assess how changes in key variables might influence economic costs and benefits from the base case scenario, including variables related to the following:

- Program size
- Biogas plant costs
- Latrine costs and adoption rates
- Fuel savings
- Latrine access
- Fertilizer values
- Health expenditure
- Health-related productivity
- Value of saved lives
- Lighting savings
- Time savings
- Environmental Benefits
- Discount rate

Table 29 provides detailed information on the scenarios evaluated.

Uganda. Under the base case scenario for Uganda with a US$200 subsidy on a $8m^3$ biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the economic BCR is 6.84 and the EIRR is 166%. Table 31 provides a more detailed picture of the economic costs and benefits. On the cost side, the largest economic cost is the biogas plant investment and program costs (75%), followed by latrine capital and program costs (14%) and hygiene materials and program cost (11%). On the benefits side, the largest financial benefit is value of saved lives (VOSL) (33%) followed by fertilizer use benefits (32%), fuel cost savings (13%), and latrine access savings (12%). GHG benefits (4%), health expenditure savings (3%), lighting benefits (2%) and local environmental benefits (1%) contribute modestly to total economic benefits.

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. As described in section 2.3, both conservative and optimistic scenarios were assessed. Figures 10 and 11 show the benefit-cost ratios and EIRRs for the sensitivity analysis. For the economic analysis, the value of key variables most affecting economic performance, in order of importance, were biogas plant and program costs, VOSL, value of slurry, discount rate and value of time savings.

The results suggest that for each dollar invested in an integrated biogas, sanitation, and hygiene program yields US$6.84 dollars in economic benefits. When the VOSL is excluded, the BCR remains robust, indicating that for each dollar spent on an integrated biogas, latrine, and hygiene programs results in US$4.56 in economic benefits.

Figure 10: Uganda sensitivity analysis for economic returns: benefit-cost ratios

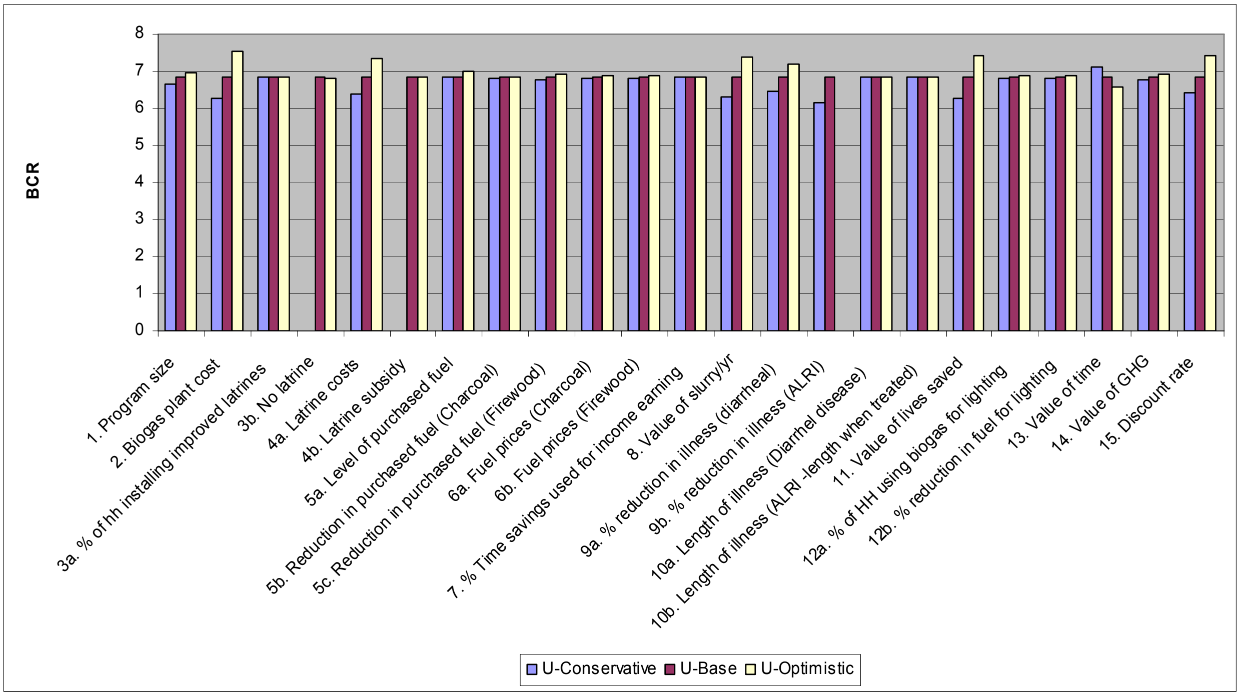
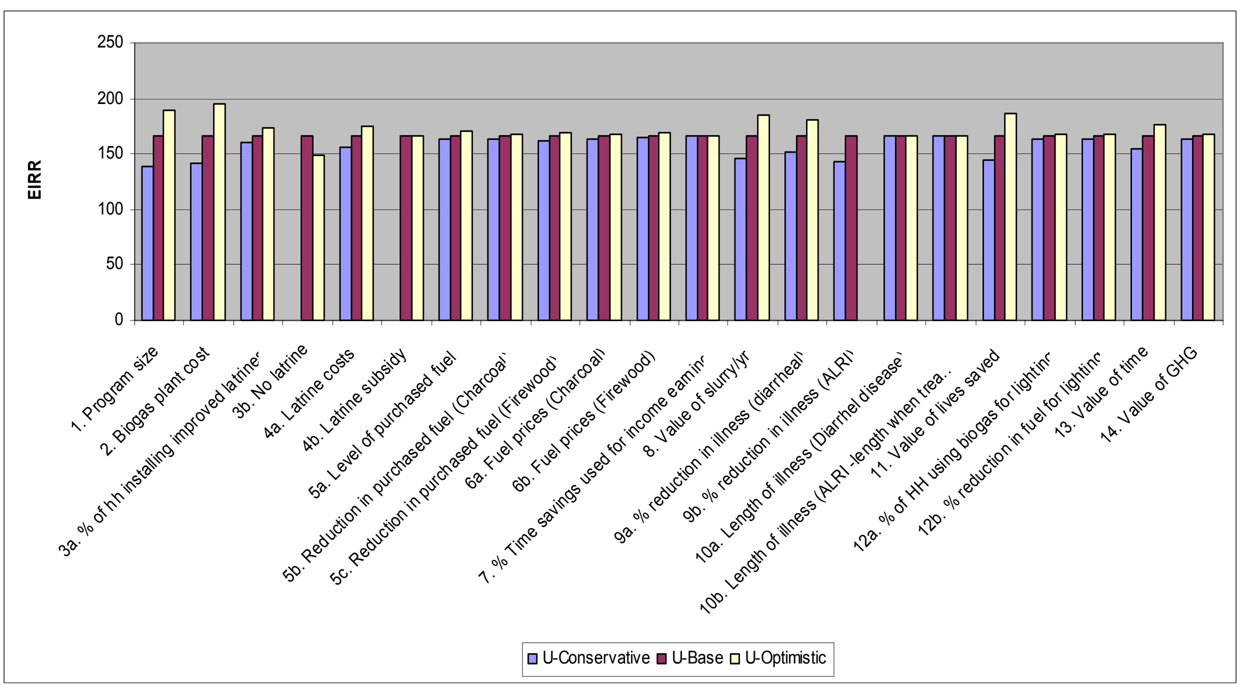


Figure 11: Uganda sensitivity analysis for economic returns: EIRRs



Rwanda. Under the base case scenario for Rwanda with a US$300 subsidy on a 6m^3 biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the economic BCR is 5.57 and the EIRR is 161%. Table 32 provides a detailed breakdown of economic costs and benefits. Of the total economic costs, the biogas plant investment and program costs constitute the largest share (76%), followed by latrines capital and program costs (12%) and hygiene materials and program costs (12%). On the benefits side, VOSL contributes (33%), followed by fertilizer use benefits (32%), fuel cost savings (13%), latrine access savings (12%), GHG emissions (4%), health expenditure savings (3%), lighting benefits (2%), and local environmental benefits (1%).

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the financial analysis. As described in section 2.3, both conservative and optimistic scenarios were assessed. Figures 12 and 13 show the benefit-cost ratios and EIRRs for the sensitivity analysis. For the economic analysis, the value of key variables most affecting economic performance, in order of importance, were biogas plant and program costs, discount rate, value of slurry, VOSL, value of time savings, and latrine costs.

The results suggest that each dollar invested in an integrated biogas, sanitation, and hygiene program yields US$5.57 dollars in economic benefits. These results remain robust when the VOSLs are excluded from the analysis. Excluding VOSL benefits, the results suggest that each dollar spent on an integrated biogas, latrine, and hygiene programs yields US$3.95 in economic benefits.

Figure 12: Rwanda sensitivity analysis for economic returns: benefit-cost ratios

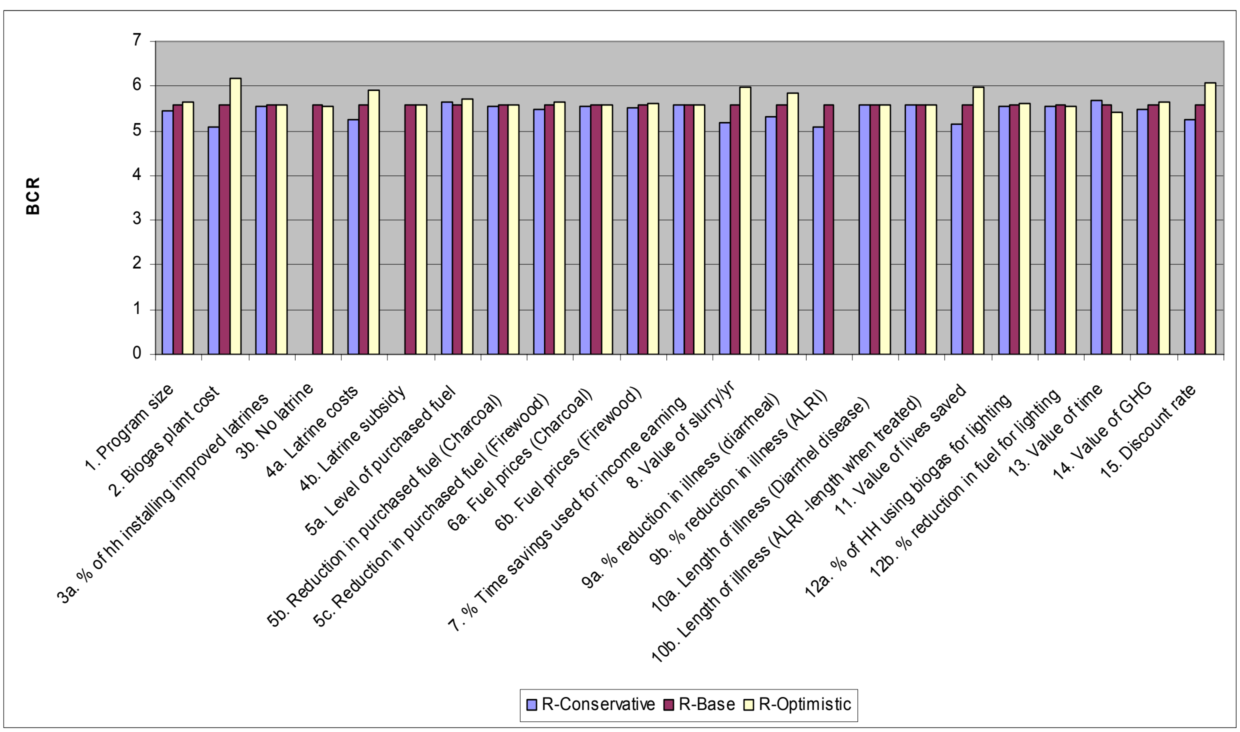
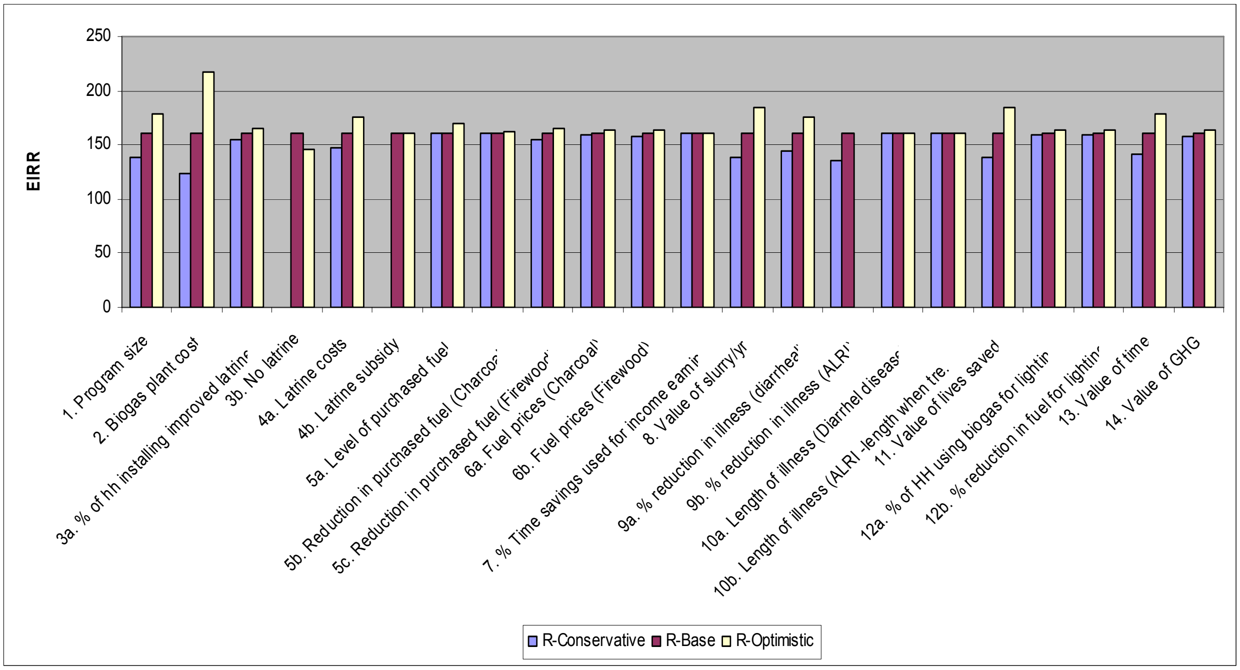


Figure 13: Rwanda sensitivity analysis for economic returns: EIRRs



Ethiopia. Under the base case scenario for Ethiopia with a US$185 subsidy on a 6m^3 biogas plant, 75% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the economic BCR is 4.52 and the FIRR is 78%. Table 33 provides a detailed breakdown of the economic costs and benefits. The composition of total economic total costs is as follows: biogas plant investment and program costs (77%), latrine investment and program costs (14%), and hygiene materials and program cost (10%). The largest economic benefit is VOSL (33%), followed by fuel cost savings (19%), fertilizer benefits (19%), latrine access savings (19%), GHG emissions reduction (5%), health expenditure savings (3%), lighting benefits (1%), and local environmental benefits (1%).

Figures 14 and 15 show the benefit-cost ratios and EIRRs for the sensitivity analysis. The sensitivity analysis shows that a number of variables have a relatively significant effect on economic performance. In order of importance, they include biogas plant investment and program costs, discount rate, VOSL, latrine costs, reduction in diarrheal disease, and value of slurry.

The results of the analysis suggest that each dollar invested in an integrated biogas, latrine, and hygiene program generates US$4.52 in economic benefits. When the VOSL is excluded, the results suggest than an integrated biogas, latrine, and hygiene program generates US$3.05 in economic benefits for every dollar invested.

Figure 14: Ethiopia sensitivity analysis for economic returns: benefit-cost ratios

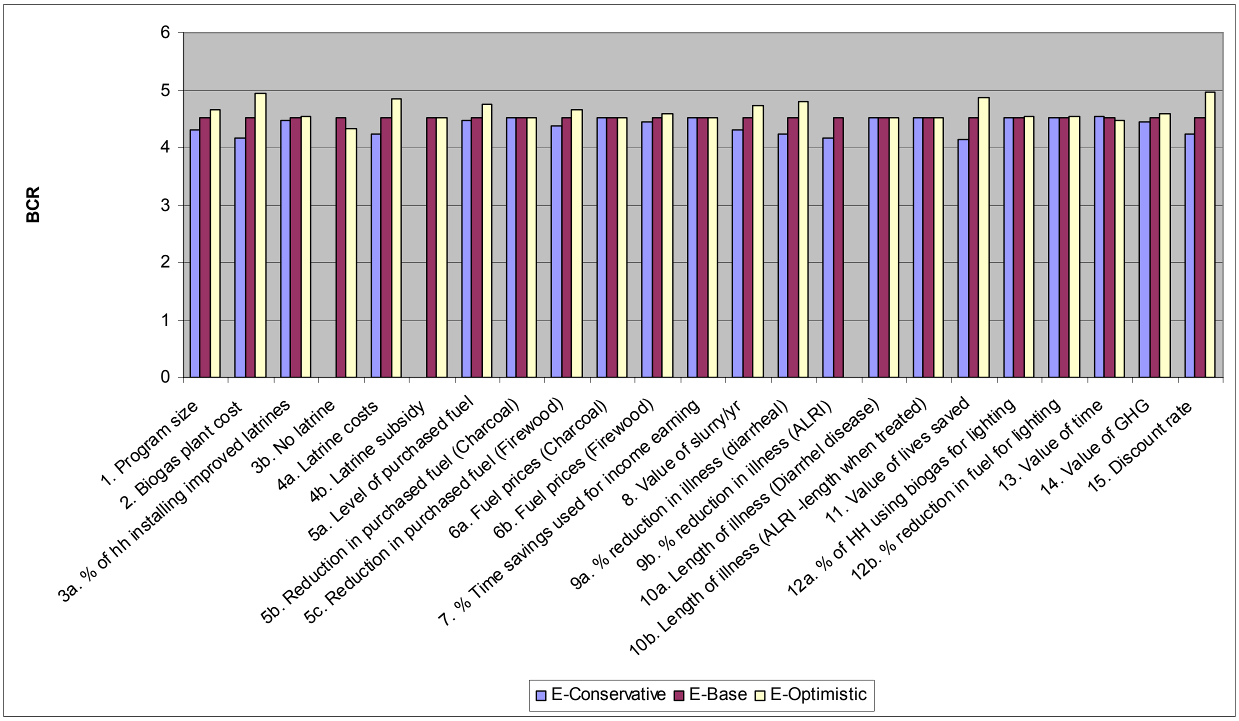
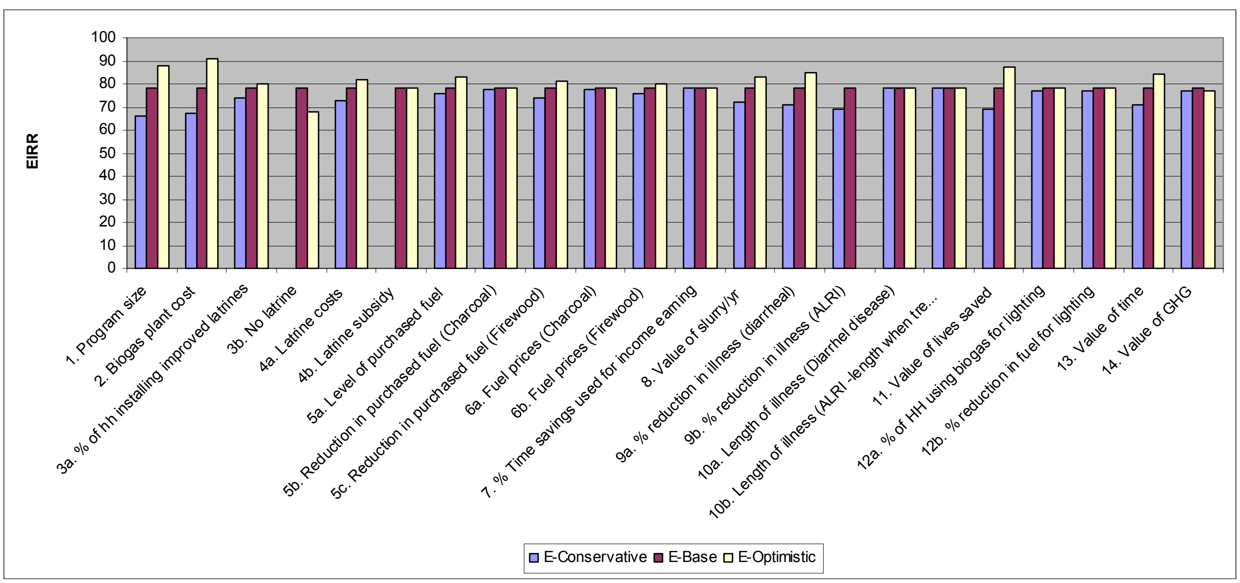


Figure 15: Ethiopia sensitivity analysis for economic returns: EIRRs



Sub-Saharan Africa. Under the base case scenario for the Sub-Saharan Africa program with a US$200 subsidy on a $6m^3$ biogas plant, 50% of households installing unsubsidized pour-flush latrines, and 60% of households adopting improved hygiene practices, the economic BCR is 6.38 and the EIRR is 178%. Table 34 provides a detailed breakdown of economic costs and benefits. On the cost side, the largest financial cost is the biogas plant investment and program costs (77%) followed by hygiene materials and program cost (12%) and latrine capital and program costs (11%). On the benefits side, the largest financial benefit is VOSL (40%), followed by value of slurry (23%), fuel cost savings (14%), latrine access savings (12%), GHG emissions reduction (5%), health expenditure savings (3%), lighting benefits (2%), and local environmental benefits (1%).

Sensitivity analysis was conducted to evaluate how changes in key variables might influence the economic analysis. Figures 16 and 17 show the benefit-cost ratios and EIRRs for the sensitivity analysis. The variables have the greatest change in results related to biogas plant and program cost, VOSL, discount rate, and diarrheal disease, and value of slurry.

The results suggest that for each dollar invested in the integrated biogas, latrine and hygiene program results in US$6.38 in economic benefits when VOSL are included and US$3.80 when VOSL are excluded.

Figure 16: sub-Saharan Africa sensitivity analysis for economic returns: benefit-cost ratios

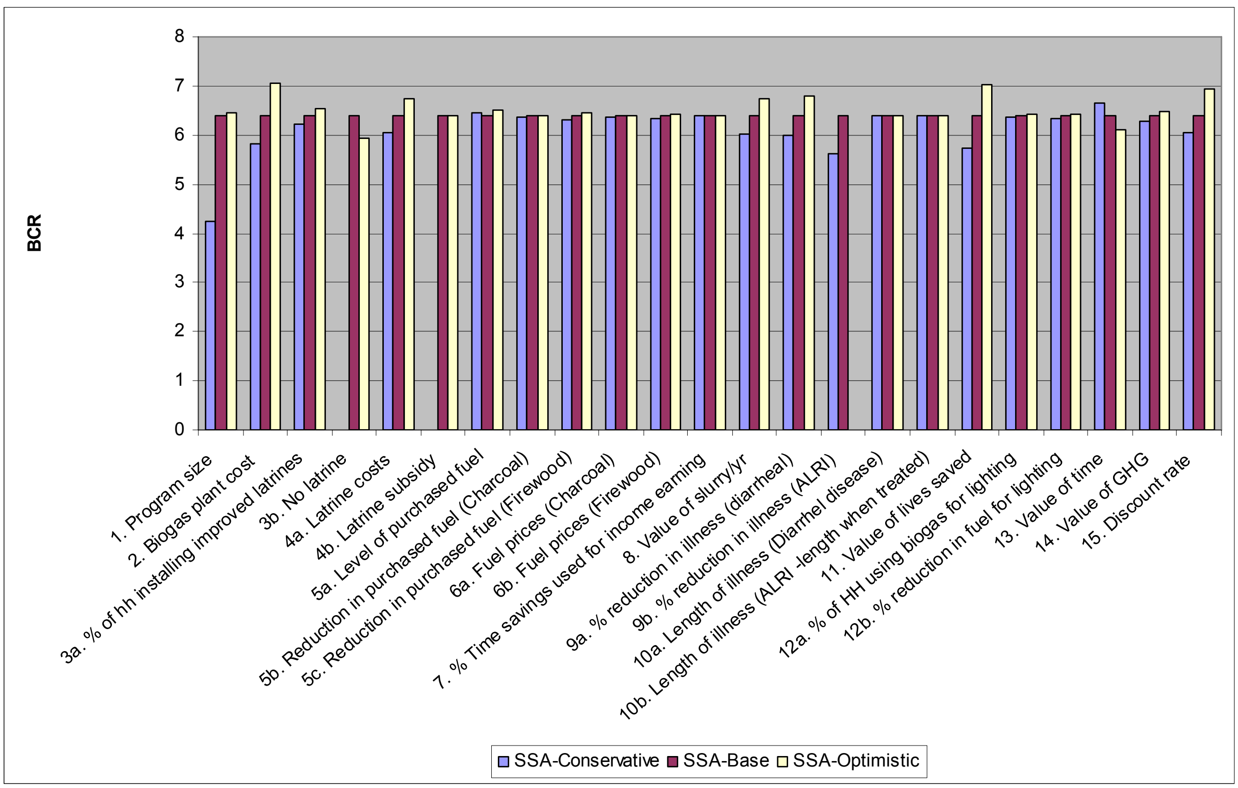
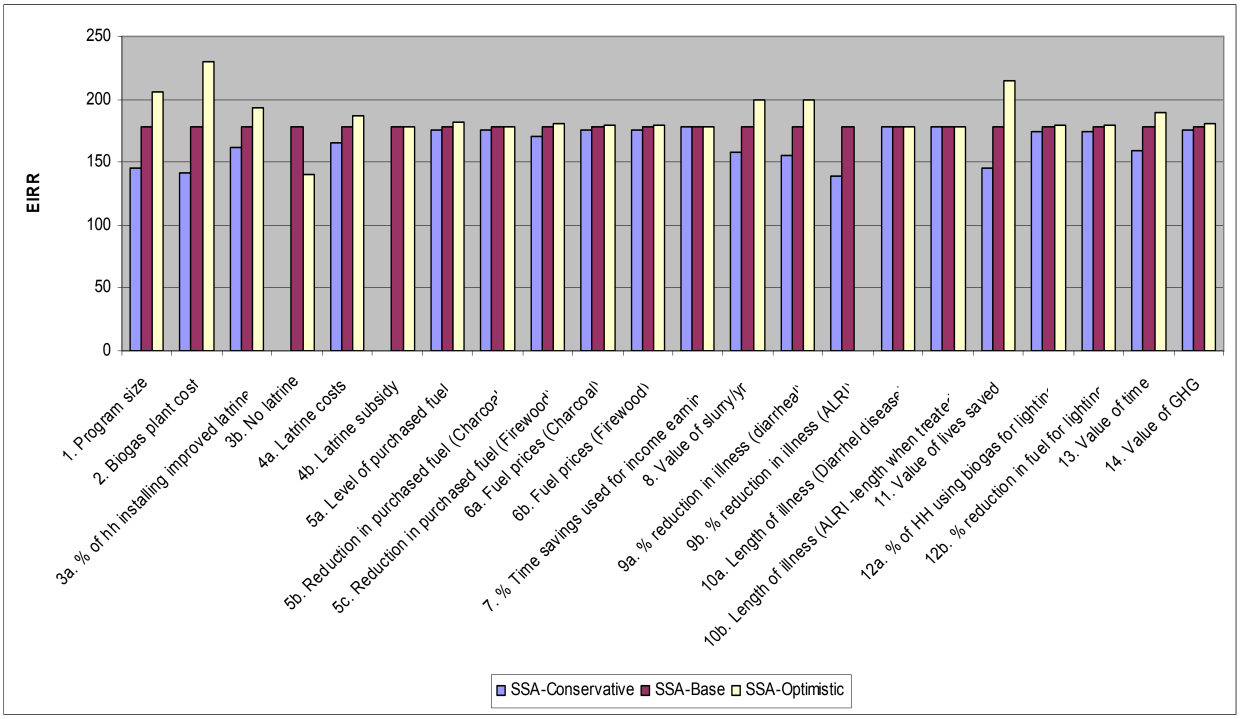


Figure 17: Sub-Saharan Africa sensitivity analysis for economic returns: EIRRs



4.0 Conclusions

This study evaluated the financial and economic costs and benefits of a large-scale integrated household-level biogas and sanitation intervention in Sub-Saharan Africa. An understanding of the costs and benefits are key ingredients in the decision-making process and the development of a successful program. The financial analysis provides insight into consumer willingness to invest in combined biogas and sanitation technologies by capturing potential net returns to participating households. The economic analysis at the programmatic level provides donors, policy makers, and sector experts with the information needed to compare alternative development investments. The analysis was conduced for the Sub-Saharan Africa Initiative as a whole as well as for Uganda, Rwanda, and Ethiopia where national programs are being considered.

The study results suggest that from a financial perspective, an integrated biogas, latrine, and hygiene program is generally financially attractive. Under the base case scenarios, with between 50–75% of households investing in a latrine, the BCRs range from 1.22 to 1.35 with FIRRs ranging from 7.5% to 10.3%. Because the financial performance was evaluated for an "average" household, further research should be undertaken to assess performance for different household types, for example, households who purchase fuel versus those that collect and those that attach latrines versus those that do not. What is clear is that the cost of the biogas plant and the latrine will be a key determining factor in the willingness of poor African households to invest. Both the plant and the latrine represent significant capital investments for low income households. In particular, the estimated cost of the pour-flush latrine may be prohibitive for many households, particularly since improved sanitation yield does not directly generate income or reduce expenditures.

From an economic perspective, an integrated biogas, latrine, and hygiene program appears very attractive. Under the base case scenario, with 50–75% of households attaching latrines, the BCRs range from 4.52 to 6.84 with EIRRs ranging from 78% to 178%. Because the value of saved lives (VOSL) constitutes such a large share of the economic benefits, the BCRs were re-estimated without including VOSL. The results of economic analysis remain robust and suggest that even in the absence of VOSL, a dollar invested in an integrated biogas, latrine, and hygiene program will result in economic benefits ranging from US$3.05 to US$4.56. The significant difference between the economic and financial analysis relates to the nature of the proposed intervention, which is characterized by relatively high capital costs, significant household energy-related expenditures (rather income generation) and substantial nonmarket benefits related especially to improvements in health, soil fertility, time savings, and drudgery, and the local and global environment.

The multifaceted nature of these economic benefits have the potential to make progress simultaneously on a number of MDGs, thereby significantly improving the lives of poor African households. Women and children in particular, have the potential to be the greatest beneficiaries of the poor because they disproportionately endure the drudgery of fuel collection and the negative health effects associated with spending hours breathing highly polluted air just to prepare their daily food for their families. Decision makers should consider the scope and extent of these benefits for improving the lives of poor African households; they provide a solid rationale for a subsidy for an integrated biogas, latrine, and sanitation program.

Given the high cost of the pour-flush latrine and the significant benefits associated with improved sanitation, sector experts should try to identify ways to reduce the cost of the latrine. Decision makers should also consider subsidies for latrines as well as for biogas plants, perhaps tied to performance incentives. Furthermore, decision makers should consider identifying ways to leverage the substantial sanitation investment that will occur in Sub-Saharan Africa in the next decade. There is a considerable gap between MDG sanitation targets and progress toward achieving these targets. To address this gap, international donors and national governments are ramping up efforts to meet MDG targets. An integrated biogas, latrine, and hygiene program could help address this gap, while leveraging planned investment.

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Annex 1

Table A. 1: Example of resources required for an 8m3 biogas plant construction: Uganda

Particulars	Unit	Quantity
Construction Materials		
1. Bricks/Stone	Pcs	1076
2. Sand	Bag/m^3	80
3. Gravel	Bag/m^3	40
4. Reinforcement rod (8mm)	Kg	16
5. Cement	Bag	16
Labor		
6.Labor	Days	23
Pipes and Fittings		
7. HDP/PVC pipe 1/2"	Meter	12
8. GI pipe 1/2"	Meter	3
9. Socket 1/2"	Pcs	2
10. GI/PVC elbow 1/2"	Pcs	5
11.Nipple 1/2"x 6"	Pcs	2
12.Teflon Tape (TT)	Pcs	3
13. GI Tee	Pcs	3
Appliances		
14. Stove-angle	Set	2
15. Mixture	Set	1
16. Paint	Liter	1
17. Inlet Pipe	Meter	4
18. Dome gas pipe	Pcs	1
19. Main Gas Valve:	Pcs	1
20. W/Drain valve	Pcs	1
21. Gas Tap	Pcs	2
22. Nylon hose pipe	Meter	3

Source: Winrock International, 2007. Uganda Feasibility Study

Table A.2. Example resources required to construct a pour-flush latrine

S.No	Description	Unit	Quantity
1	Mason	day	3
2	Labor	day	6
3	Cement	Bags	4
4	Sand	Bags	0.8
5	Aggregates	Bags	0.2
6	Brick	Pcs	900
7	Toilet Pan set	Set	1
8	Fittings materials	Lumpsum	1
9	GI Sheet	Pcs	2
10	Wooden planks	Pcs	4
11	Wood	Cuft	2
12	Carpenter	days	1
13	Helper	days	1
	Total		
Note: Rates not available in Uganda was put as double the rate in Nepal			

Table A.3: Case fatality rate for diarrheal disease in Africa, by age group

Region	Age group			
	0 to 1	1 to 4	5 to 14	15 +
AFR-D	0.0013	0.0013	0.0004	0.0004
AFR-E	0.0012	0.0012	0.0004	0.0003

Table A.4: Sensitivity analysis for financial returns: benefit-cost ratios

Financial Analysis: Benefit Cost Ratios												
Sensitivity Analysis Scenario	**Uganda**			**Rwanda**			**Ethiopia**			**Sub-Saharan Africa**		
	Conservative	**Base**	**Optimistic**	**Conservative**	**Base**	**Optimistic**	**Conservative**	**Base**	**Optimistic**	**Conservative**	**Base**	**Optimistic**
2. Biogas plant cost	1.04	1.25	1.57	1.07	1.32	1.73	1.13	1.35	1.69	1	1.22	1.57
3a. % of hh installing improved latrines	1.42	1.25	1.12	1.48	1.32	1.19	1.51	1.35	1.28	1.36	1.22	1.12
3b. No latrine		1.25	1.77		1.32	1.82		1.35	1.95		1.22	1.62
4a. Latrine costs	1.09	1.25	1.47	1.16	1.32	1.53	1.17	1.35	1.61	1.09	1.22	1.4
4b. Latrine subsidy		1.25	1.39		1.32	1.46		1.35	1.51		1.22	1.33
5a. Level of purchased fuel	1.09	1.25	1.48	1.24	1.32	1.63	1.04	1.35	1.82	1.14	1.22	1.41
5b. Reduction in purchased fuel (Charcoal)	1.2	1.25	1.26	1.29	1.32	1.33	1.35	1.35	1.35	1.19	1.22	1.24
5c. Reduction in purchased fuel (Firewood)	1.13	1.25	1.36	1.21	1.32	1.44	1.13	1.35	1.57	1.13	1.22	1.32
6a. Fuel prices (Charcoal)	1.19	1.25	1.32	1.27	1.32	1.38	1.35	1.35	1.36	1.17	1.22	1.28
6b. Fuel prices (Firewood)	1.18	1.25	1.38	1.23	1.32	1.42	1.15	1.35	1.55	1.16	1.22	1.29
7. % Time savings used for income earning	1.18	1.25	1.31	1.23	1.32	1.41	1.27	1.35	1.44	1.15	1.22	1.3
12a. % of HH using biogas for lighting	1.18	1.25	1.33	1.25	1.32	1.4	1.33	1.35	1.38	1.16	1.22	1.3
12b. % reduction in fuel for lighting	1.17	1.25	1.33	1.25	1.32	1.4	1.33	1.35	1.38	1.16	1.22	1.3
13. Value of time	1.11	1.25	1.25	1.16	1.32	1.34	1.25	1.35	1.42	1.08	1.22	1.24
15. Discount rate	1.14	1.25	1.37	1.21	1.32	1.45	1.24	1.35	1.48	1.12	1.22	1.34

Table A.5: Sensitivity analysis for financial returns: FIRRs

Financial Analysis: IRRs Sensitivity Analysis Scenario	Uganda			Rwanda			Ethiopia			Sub-Saharan Africa		
	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic
2. Biogas plant cost	3.7	8	15.5	4.3	9.5	20	5.7	10.3	18.5	3	7.5	15.5
3a. % of hh installing improved latrines	10.7	8	5.5	12.3	9.5	7.3	12.7	10.3	9	9.7	7.5	5.5
3b. No latrine		8	15.5		9.5	16.5		10.3	18.3		7.5	13
4a. Latrine costs	5	8	11.5	6.7	9.5	13	7	10.3	14.2	5	7.5	10.3
4b. Latrine subsidy		8	10.3		9.5	11.7		10.3	12.7		7.5	9.3
5a. Level of purchased fuel	5	8	12.5	8	9.5	15.5	4	10.3	19.3	5.8	7.5	11
5b. Reduction in purchased fuel (Charcoal)	7.3	8	8.3	9	9.5	9.8	10.3	10.3	10.3	7	7.5	7.9
5c. Reduction in purchased fuel (Firewood)	5.7	8	10.3	7.5	9.5	11.7	6	10.3	14.5	5.8	7.5	9.3
6a. Fuel prices (Charcoal)	7	8	9.5	8.5	9.5	10.7	10.2	10.3	10.4	6.5	7.5	8.7
6b. Fuel prices (Firewood)	6.7	8	10.7	7.7	9.5	11.5	6.3	10.3	14	6.3	7.5	9
7. % Time savings used for income earning	6.8	8	9.3	7.8	9.5	11.3	8.7	10.3	12	6	7.5	9
12a. % of HH using biogas for lighting	6.7	8	9.5	8.3	9.5	11.3	10	10.3	10.7	6.3	7.5	9
12b. % reduction in fuel for lighting	6.7	8	9.5	8.3	9.5	11.3	10	10.3	10.7	6.3	7.5	9
13. Value of time	5.3	8	8	6.3	9.5	10	8.3	10.3	11.5	4.7	7.5	7.9

Table A.6: Sensitivity analysis for economic returns: benefit-cost ratios

Economic Analysis: Benefit Cost Ratios												
Sensitivity Analysis Scenario	Uganda			Rwanda			Ethiopia			Sub-Saharan Africa		
	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic
1. Program size	6.66	6.84	6.95	5.46	5.57	5.64	4.3	4.52	4.65	4.25	6.38	6.46
2. Biogas plant cost	6.27	6.84	7.53	5.07	5.57	6.18	4.17	4.52	4.93	5.83	6.38	7.05
3a. % of hh installing improved latrines	6.83	6.84	6.85	5.56	5.57	5.58	4.46	4.52	4.54	6.22	6.38	6.53
3b. No latrine		6.84	6.8		5.57	5.54		4.52	4.34		6.38	5.94
4a. Latrine costs	6.4	6.84	7.34	5.26	5.57	5.92	4.23	4.52	4.84	6.06	6.38	6.74
4b. Latrine subsidy		6.84	6.84		5.57	5.57		4.52	4.52		6.38	6.38
5a. Level of purchased fuel	6.86	6.84	7	5.63	5.57	5.72	4.48	4.52	4.75	6.45	6.38	6.52
5b. Reduction in purchased fuel (Charcoal)	6.82	6.84	6.84	5.56	5.57	5.57	4.51	4.52	4.52	6.37	6.38	6.39
5c. Reduction in purchased fuel (Firewood)	6.76	6.84	6.92	5.47	5.57	5.66	4.38	4.52	4.65	6.3	6.38	6.46
6a. Fuel prices (Charcoal)	6.82	6.84	6.87	5.55	5.57	5.59	4.51	4.52	4.52	6.36	6.38	6.4
6b. Fuel prices (Firewood)	6.81	6.84	6.89	5.53	5.57	5.61	4.44	4.52	4.59	6.35	6.38	6.41
7. % Time savings used for income earning	6.84	6.84	6.84	5.57	5.57	5.57	4.52	4.52	4.52	6.38	6.38	6.38
8. Value of slurry/yr	6.29	6.84	7.38	5.17	5.57	5.97	4.3	4.52	4.73	6.01	6.38	6.75
9a. % reduction in illness (diarrheal)	6.47	6.84	7.21	5.3	5.57	5.84	4.23	4.52	4.8	5.98	6.38	6.79
9b. % reduction in illness (ALRI)	6.17	6.84		5.09	5.57		4.16	4.52		5.63	6.38	
10a. Length of illness (Diarrhel disease)	6.84	6.84	6.84	5.57	5.57	5.57	4.51	4.52	4.52	6.38	6.38	6.38
10b. Length of illness (ALRI -length when treated)	6.84	6.84	6.84	5.57	5.57	5.57	4.51	4.52	4.52	6.38	6.38	6.38
11. Value of lives saved	6.27	6.84	7.41	5.16	5.57	5.97	4.15	4.52	4.88	5.74	6.38	7.03
12a. % of HH using biogas for lighting	6.81	6.84	6.87	5.54	5.57	5.6	4.51	4.52	4.53	6.36	6.38	6.41
12b. % reduction in fuel for lighting	6.81	6.84	6.87	5.54	5.57	5.54	4.51	4.52	4.53	6.35	6.38	6.41
13. Value of time	7.11	6.84	6.56	5.69	5.57	5.41	4.54	4.52	4.48	6.66	6.38	6.1
14. Value of GHG	6.76	6.84	6.92	5.49	5.57	5.65	4.44	4.52	4.59	6.29	6.38	6.47
15. Discount rate	6.44	6.84	7.43	5.26	5.57	6.06	4.24	4.52	4.97	6.04	6.38	6.94

Table A.7: Sensitivity analysis for economic returns: EIRRs

Economic Analysis:IRRs Sensitivity Analysis Scenario	Uganda			Rwanda			Ethiopia			Sub-Saharan Africa		
	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic	Conservative	Base	Optimistic
1. Program size	139	166	189	139	161	179	66	78	88	145	178	206
2. Biogas plant cost	142	166	195	123	161	217	67	78	91	141	178	230
3a. % of hh installing improved latrines	160	166	173	155	161	165	74	78	80	162	178	193
3b. No latrine		166	149		161	146		78	68		178	140
4a. Latrine costs	156	166	175	148	161	175	73	78	82	165	178	187
4b. Latrine subsidy		166	166		161	161		78	78		178	178
5a. Level of purchased fuel	164	166	170	160	161	169	76	78	83	176	178	182
5b. Reduction in purchased fuel (Charcoal)	164	166	167	160	161	162	77.5	78	78	176	178	178.5
5c. Reduction in purchased fuel (Firewood)	162	166	169	155	161	165	74	78	81	171	178	181
6a. Fuel prices (Charcoal)	164	166	168	159	161	163	77.5	78	78	175	178	179
6b. Fuel prices (Firewood)	165	166	169	158	161	163	76	78	80	175	178	179
7. % Time savings used for income earning	166	166	166	161	161	161	78	78	78	178	178	178
8. Value of slurry/yr	146	166	185	138	161	184	72	78	83	158	178	200
9a. % reduction in illness (diarrheal)	152	166	180	145	161	176	71	78	85	155	178	199
9b. % reduction in illness (ALRI)	143	166		135	161		69	78		139	178	
10a. Length of illness (Diarrhel disease)	166	166	166	161	161	161	78	78	78	178	178	178
10b. Length of illness (ALRI -length when treated)	166	166	166	161	161	161	78	78	78	178	178	178
11. Value of lives saved	145	166	187	139	161	185	69	78	87	145	178	215
12a. % of HH using biogas for lighting	164	166	168	159	161	163	77	78	78	174	178	179
12b. % reduction in fuel for lighting	164	166	168	159	161	163	77	78	78	174	178	179
13. Value of time	155	166	176	142	161	178	71	78	84	159	178	190
14. Value of GHG	164	166	168	158	161	163	77	78	77	175	178	180