Impact evaluation of Netherlands supported programmes in the area of Energy and Development Cooperation in Rwanda

Impact Evaluation of Rwanda's National Domestic Biogas Programme

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This report is part of an evaluation commissioned by the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. It belongs to a series of impact evaluations of renewable energy and development programmes supported by the Netherlands, with a focus on the medium and long term effects of these programmes on end-users or final beneficiaries. A characteristic of these studies is the use of mixed methods, that is, quantitative research techniques in combination with qualitative techniques. The purpose of the impact evaluations is to account for assistance provided and to draw policy lessons. The results of these evaluations will serve as inputs to a policy evaluation of the "Promoting Renewable Energy Programme" (PREP) to be concluded in 2014.

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1. Introduction

In 2006, the Government of Rwanda with the support of SNV Netherlands Development Organisation launched its National Domestic Biogas Programme (NDBP). The programme is implemented by the government's Ministry of Infrastructure (MININFRA) and received financial and technical support from the Energising Development Programme (EnDev), a Dutch-German partnership funded by the Directorate-General for International Cooperation of the Dutch Ministry of Foreign Affairs (DGIS) and executed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The overall objective of the programme is 'to develop a commercially viable and environmentally sustainable market-oriented biogas sector, resulting in the reduction of biomass resource depletion while providing a significant improvement in the quality of life of the families concerned' (Government of Rwanda, 2007).[2]

To elaborate, several factors motivated the decision to invest in the development of this sector. For instance, it is expected that the use of biogas where the primary input is animal manure, will lead to a reduction in the use of other fuel sources such as firewood and at the same time provide a cheaper and cleaner fuel for household cooking and lighting use.[3] At the same time, the by-product of the production process, bio-slurry, may be used as a fertiliser.[4] Additional benefits expected due to the development of a market-oriented sector are the creation of new economic activities and job creation.

At inception, NDBP set a target of building 15,000 high-quality family-sized (up to 10 m^3) digesters by the end of 2011. However, a mid-term review conducted in late 2009 led to a rescaling of the target to 5,000 digesters and in 2010 during the Rwandan National Leadership Retreat a new target of 3,000 digesters was proposed. According to information from NDBP, by mid-2012, around 1,800 digesters spread over 30 districts had been built.

[2] According to Dekelver, Ndahimana and Ruzigana (2006), a market-oriented approach or "development through the market" is an approach where the focus is on the potential user, and goods and services are designed to enhance technology adoption. This approach includes several activities which are oriented towards developing a market for biogas and includes among others:
•"the establishment of consumer confidence through a reliable product, promotion activities, the initial incentive of a subsidy (until sufficient market penetration has been achieved) and provision of credit facilities, a long-term demand for the product is created and therewith a promising market for construction companies;
• through demand generation and a range of trainings (technical, marketing, management) new companies are supported and offered the perspective to grow and develop;
• by conducting applied research, the product is modified to meet the exact need of the consumer, therewith improving the quality-price ratio;
• by establishing national standards, harmonization can be achieved in promotion, training and construction, leading to lower overhead costs while the user is ensured of a minimum quality;
• regulatory and control mechanisms through which a level of customer protection is achieved and therewith again long-term confidence of the market in the product;
• organizational and institutional strengthening for development of the sector".

[3] The Ghana based Kumasi Institute of Technology, Energy and Environment (2008) and a group of biogas researchers (Biogas Team, 2007) have estimated that by 2050, the smoke from cooking stoves will release about 7 billion tons of carbon in the form of greenhouse (GHG) emissions. If left to decompose in open air, cow manure emits methane and nitrous oxide, contributing substantially to global GHG emissions. Both methane and nitrous oxide are powerful GHG, with approximately 21 and 310 times the global warming potential of CO_2, respectively (Cuéllar and Webber, 2008). The anaerobic processes taking place in a digester produce a methane-rich gas that when burnt emits CO_2 resulting in a substantial net decrease in CO_2 equivalent emissions. Thus, if employed on a large scale, and especially if used instead of fossil fuels, the adoption of digesters can contribute to the abatement of anthropogenic GHG emissions.

[4] Although evidence is limited, according to Dekelver *et al.* (2005) bio-slurry is a useful organic fertilizer and a few field-based trials have displayed that bio-slurry has a positive impact on crop yields (Arthur *et al.*, 2011; Gautam *et al.*, 2009; Garfi *et al.*, 2011). However, effects are crop and context-specific. See also footnote 46.

Despite the existence of several initiatives to promote biogas, systematic analyses of the effects of access to biogas are limited.[5] The aim of this report is to provide such an analysis. This report deals with a series of questions - as outlined in the terms of reference, however, the main objective is to assess the impact of access to biogas provided through NDBP (section 2.3 of terms of reference) on various indicators of household welfare.[6] These indicators include household energy expenditures, consumption of traditional fuels such as firewood and charcoal, time-use patterns, indoor air pollution and health effects and the use of bio-slurry and crop yields.[7] To meet its objectives the report draws upon key informant interviews with a range of stakeholders conducted in May 2012, a cross-sectional household survey of 600 households canvassed in June-July 2012, and a survey undertaken in 20 villages with a relatively high concentration of digesters, in November 2012. The analysis reported in the paper focuses on digesters constructed and activities undertaken till the end of December 2011.

Methodologically, the report relies on cross-section data –that is, a sample of data collected at one point in time— and a comparison of treatment and control groups, that is, households who have a digester and those who don't but have expressed an interest in having a digester (potential applicants) to identify the impact of the NDBP on variables of interest. Parametric (ordinary least squares) and non-parametric (propensity score matching) methods are used to identify impact.

The report unfolds by providing, in Section 2, a brief country background, a discussion of the energy sector in Rwanda and describing the main features of the NDBP. Section 3 lists the evaluation questions and discusses the methodological approach while Section 4 describes the data. Section 5 examines the validity of the empirical strategy, and presents estimates. Section 6 concludes the report.

2. The context and the intervention

2.1. Regional context

Rwanda is located in the Great Lakes region of east-central Africa, a few degrees south of the Equator. With 10.6 million inhabitants, it is similar to Belgium in terms of dimension and population and is the most densely populated country in Africa. Since its administrative reorganization in 2006, the country has been subdivided into 5 provinces, 30 districts and 415 sectors - areas comprising on average 15,000 to 20,000 people. These are further subdivided into cells and so-called 'umudugudus' – which are centres that regroup homes into village clusters around basic infrastructure, as opposed to traditionally dispersed settlements.

After a long and difficult process of recovery from the genocide that devastated the country's human, physical and social capital in 1994, Rwanda is now firmly on the path of resurgence and economic

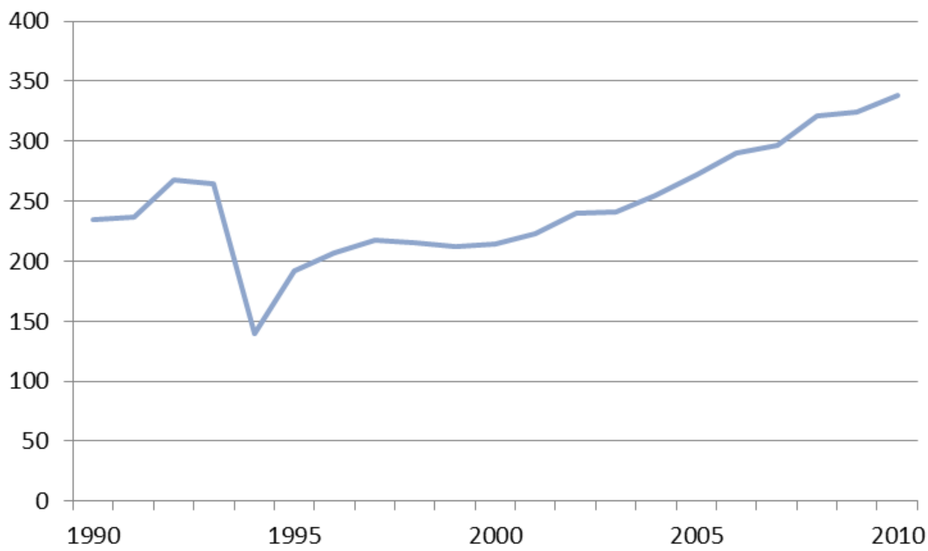
[5] Exceptions are Katuwal *et al*. (2009) and Gautam *et al*. (2009) who provide analyses for Nepal and show that access to biogas leads to time-savings especially for women and children which in turn may lead to an increase in recreational and income-generating activities. Arthur *et al*. (2011) provide similar evidence from Ghana and according to the Africa Development Fund (2008) in Ghana, access to biogas and the reduction in time spent on gathering firewood has been associated with an increase in child school attendance.

[6] See Terms of reference, dated 17th January 2012.

[7] Effluents generated by the combustion of firewood are among the main reasons for eye infections and acute respiratory infections. The use of biogas which is smokeless may be expected to reduce the incidence of such diseases especially for those spending more time in the kitchen. In addition to these immediate effects, in rural Nepal, Bajgain *et al.* (2005) argue that as a consequence of improved hygiene, the use of digesters has worked towards decreasing the occurrence of contagious diseases such as cholera, diarrhoea and tuberculosis.

development. Primary export goods are coffee and tea, with the addition in recent years of minerals and flowers. At current prices, per capita GDP in 2010 was USD 530 and between 2000 and 2010 the country recorded an annual per capita real GDP growth rate of 4.4 percent (see Figure 1). Consistent with the increase in incomes, there have been improvements in socio-economic conditions captured by, for instance, increases in life-expectancy (see Figure 2) and a reduction in malnourishment (a decline from 57 percent in 1997 to 32 percent in 2008). Notwithstanding this recent growth performance, in 2005, the latest year for which information is available, the incidence of poverty was pegged at 64.2 percent in rural areas and 23.2 percent in urban areas. The bulk of the population lives in rural areas (82.5 percent in 2005) which account for about 92 percent of the poor. (All figures from World Development Indicators 2011).

Figure 1: Per capita gross domestic product in constant 2000 USD

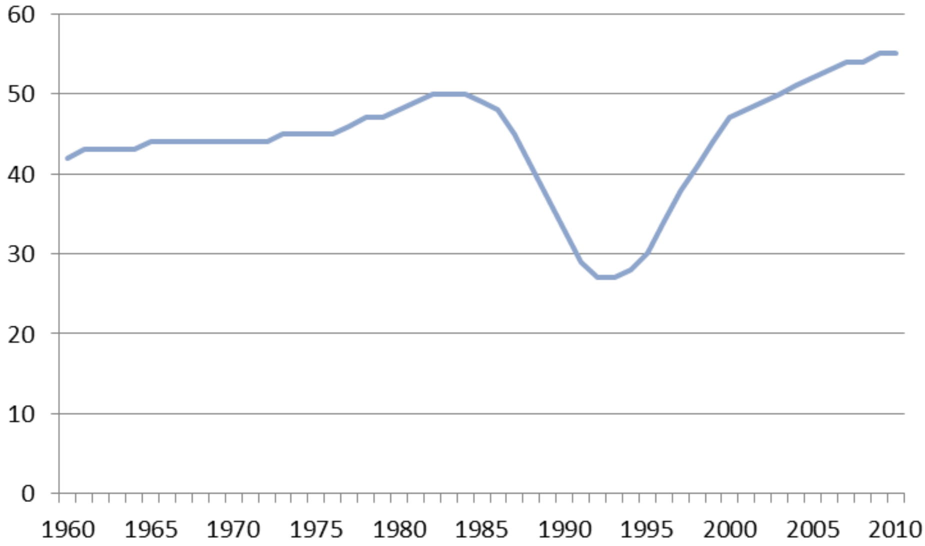


Source: World Development Indicators 2011.

Rwanda's economy is mostly agrarian with 80 percent of the population engaged in agricultural activities and with agriculture accounting for 40 percent of GDP. The service sector and the industrial sector contribute 39 percent and 20 percent of GDP, respectively, but employ only 6 and 2 percent of the labour force (National Institute of Statistics Rwanda 2000). In terms of demographics, the country has a high population density (430 people per km^2) and high fertility rates (about 5 births per fertile woman).

In its planning document called *Vision 2020*, the government has formulated its long term strategy for the development of the country. The objective is to increase per capita income to USD 900 by 2020 based on a transition from subsistence farming to higher value added agriculture and non-farm activities. This ambitious goal is expected to be realized by promoting private sector development and the transformation of the country from an agricultural based economy to a knowledge based society in which the majority of employment comes from the industrial and service sectors (Ministry of Finance and Economic Planning, 2000).

Figure 2: Life expectancy at birth



Source: World Development Indicators 2011.

2.2. Energy context

Given the nature of the intervention under study, this section focuses mainly on household energy use for cooking and lighting.[8] Biomass, in the form of wood, charcoal or agricultural residues, is the main energy source for cooking purposes, both in rural and urban areas. According to MINECOFIN (2003), nationwide, 85 percent of all households rely mainly on wood; the figure is 52 percent in urban Rwanda and 91 percent in rural areas. The use of gas and electricity for cooking is negligible. With regard to lighting, in 2002, about 5 percent of households had access to grid powered-electricity, in 2009 it rose to 6 percent[9] and in September 2012, there were 331,000 households connected to the grid or a household electrification rate of 14 to 16 percent.[10] While updated figures on access to other lighting sources are awaited (information has been collected in a census conducted in 2012), at least according to currently available information, the majority of households rely on oil/wicker lamps (64 percent). Wood is the main source for lighting for 16 percent (see Table 1).

A more recent analysis based on Rwanda's household conditions surveys, although one which does not distinguish between energy for cooking and lighting, underlines the reliance on bio-mass to meet energy

[8] Firewood is used not only by households, but also by some industries and institutions. Information on the amount of firewood consumed by industries and institutions is scanty and not very informative. For instance, Hategeka (1997) reports that a substantial amount of firewood is used by bakeries, brickworks, schools and restaurants.

[9] See http://mininfra.gov.rw/index.php?option=com_content&task=view&id=114&Itemid=142. Accessed on February 3, 2012.

[10] Information on total number of households connected is form the World Bank. Estimates of average household size vary from 4.3 to 5. Sources: Total population from the '2012 Population and Housing Census', http://statistics.gov.rw/publications/2012-population-and-housing-census-provisional-results; households with electricity connections from http://www.worldbank.org/projects/P111567/rwanda-electricity-access-scale-up-sector-wide-approach-swap-development-project?lang=en, information on household size from, http://www.cleancookstoves.org/countries/africa/rwanda.html and http://www.statistics.gov.rw/publications/statistical-yearbook-2012. Accessed on April 19, 2013.

needs. At the national level, 88 percent of households rely mainly on wood while 8 percent rely on charcoal to meet their energy needs (see Table 2).

Table 1: Main source of energy for cooking and lighting in urban and rural areas of Rwanda in 2002

Energy type	Energy use					
	Cooking			Lighting		
	Urban	Rural	National	Urban	Rural	National
Electricity	0.7	0.0	0.1	25.9	0.6	4.6
Private hydro-electric source				0.1	0.0	0.1
Solar, plates/electric generator				0.2	0.1	0.1
Gas	0.2	0.0	0.1			
Kerosene/bush lamp	0.2	0.1	0.1	26.1	8.9	11.6
Lampion/wicker				41.7	68.7	64.4
Candle				1.8	0.2	0.5
Firewood/wood	52.2	91.0	84.9	2.4	18.3	15.8
Charcoal	41.3	1.2	7.5			
Vegetal materials	3.4	7.1	6.5			
Other	1.3	0.1	0.3	0.7	2.4	2.2
Not specified	0.7	0.4	0.5	1.1	0.8	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: MINECOFIN, 2003.

Table 2: Main source of energy Rwanda 1999-2000 and 2005-2006

	EICV1	EICV2	EICV1	EICV2	EICV1	EICV2	EICV1	EICV2
	City of Kigali		Other urban		Rural		National	
Wood	21.4	23.1	81.7	73.7	97.7	95.5	90.4	88.2
Charcoal	75.8	72.4	16.3	19.6	19.6	1.1	8.0	7.9
Gas	0.5	0.2	0.2	0.1	0.1	n/a	0.1	0.0
Electricity	0.5	0.2	0.2	0.3	0.3	0.0	0.2	0.1
Kerosene	0.3	0.8	0.1	0.3	0.3	0.0	0.1	0.1
Miscellaneous burning	0.0	0.1	0.9	2.5	2.5	3.0	0.7	2.7
Other	1.5	3.3	0.6	3.4	3.4	0.4	0.6	0.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: EUEI-PDF GTZ MARGE (2009). Based on household condition surveys EICV1 (1999-2000) and EICV2 (2005-2006).

While figures on the amount of firewood consumption are dated, a 1993 survey estimated that the average per capita daily consumption was 1.3 kg of air-dried wood (Hategeka 1997). Various studies show that even in urban areas, where the price of firewood is at times higher compared to modern alternatives, households still prefer to purchase firewood as: i) the supply is secure, ii) firewood may be purchased in small, affordable quantities at the local market and iii) the use of firewood does not require any expensive initial investment in cooking devices (Leach and Mearns, 1988; Ndayambaje and Mohren, 2011). In rural areas, households have limited alternatives to firewood and charcoal for cooking, in addition, the existing alternatives are comparatively expensive, while firewood may be collected free of charge (GTZ, 2008).

The country relies on imports for all its petroleum related products which makes them expensive and inaccessible for the bulk of the population. Price inaccessibility to petroleum-based fuels and an overwhelming reliance on wood as an energy source has been recognized as a key development challenge by the government. *Vision 2020*, emphasizes the need for economic growth, for increasing private investment and economic transformation, and singles out reliable and affordable energy supply as a key ingredient needed to sustain development. In order to achieve this economic transformation, the need to increase and diversify energy production has been stressed. Among other targets, *Vision 2020* envisages that at least 35 per cent of the population will be connected to electricity which is expected to decrease the share of population using firewood as their main energy source to 50 percent (Ministry of Finance and Economic Planning, 2000).[11]

Alternative sources of power and industrial heat such as hydropower, methane and peat are being explored (Table 3). For instance, Rwanda has access to peat reserves estimated at 155 million tonnes which has the potential to replace the use of biomass (MININFRA 2008). It has been estimated that about a third is extractable and can be commercially used as a source of industrial heat or for electricity production. While power production from peat is still in an early stage, the use of peat has been tested in community institutions, for brick making and in cottage industries (MININFRA 2009).[12] Geothermal resources are available in the country in the form of hot springs along Lake Kivu. Technical exploration studies are being conducted.

Table 3: Sites for potential development of energy

Identified sites	Capacity
Hydro power (in MW)	
Nyabarongo	27.5
Rukarara	9
Mukungwa II	3
Rusomo falls (shared)	60
Ruzizi III (shared/under exploitation)	500/72
Microhydro power (in MW)	
Many locations all over Rwanda	30-500
Methane (inMW)	
Lake Kivu	170-340
Peat (in Million tonnes)	155
Solar (in KWh /m2/ day)	5.5
Wood- estimated (in Million tonnes)	2.3

Source: Electrogaz (2008).

Against this background, the effort Rwanda is making to develop the biogas sector and undertaking other initiatives may be characterised as an attempt to diversify energy sources, reduce reliance on firewood consumption and at the same time help preserve forests/the environment. For instance, in order to limit the use of firewood, the Ministry of Infrastructure supported by the EU Energy Initiative Partnership Dialogue Facility/GIZ has prepared a Biomass Energy Strategy (BEST) which aims at i) reducing the firewood consumption with a "large scale dissemination of efficiency stoves and improved charcoal-making techniques" and ii) substituting the firewood use with alternatives represented by "biogas, carbonized peat and papyrus and other biomass briquettes, liquefied petroleum gas (LPG), methane gas and solar energy".[13] As a way to promote these policies, the Ministry of Infrastructure contracted Chardust Limited, an international company based in Kenya, in 2009 for the pilot production and testing of charcoal from peat and papyrus to replace charcoal produced from wood. In addition, the Ministry of Infrastructure is carrying out a campaign to promote the LPG use in households and community institutions.

With regard to biogas in particular, access to the technology and the use of biogas has a relatively long history in the country and has been available since the end of the 1990s. Initially, the use of biogas was

[11] MININFRA's 2011 Energy Strategy of 2011 sets out a connection target of 70 percent by 2017.

[12] Peat is not popular for household use as peat smoke tends to be thicker than smoke released by wood and it tends to smoulder rather than burn with an open flame. For more details see www.publichealth.wa.gov.au/cproot/1415/2/Minimising_the_Impacts_of_Peat_Smoke.pdf. Accessed on April 13, 2013.

[13] See http://rwandaenergy.com/2011/12/renewable-energy-an-alternative-to-save-forestry/, accessed on the 1st of November 2012.

promoted at large institutional entities, especially prisons, not only for reducing firewood but in particular to enhance hygiene and sanitation. Indeed the government's biogas program for prisons has drawn international attention and recognition.[14] In 2000, a number of other institutions such as schools and hospitals also built biogas plants and in 2006 the government launched the National Domestic Biogas Programme (NDBP).

Despite recognizing the need for energy diversification, since 2000 when the objectives of *Vision 2020* were set out, patterns of energy consumption have not changed dramatically, especially in terms of firewood consumption. Indeed it seems that in recent years the consumption of traditional biomass has increased in both urban and rural areas and the continuous lack of alternative energy sources such as LPG or electricity is leading to increased pressure on available forest resources (MININFRA, 2008; Ndayambaje and Mohren, 2011). At the same time, it is becoming particularly challenging for rural dwellers to satisfy their daily requirements of firewood (FAOSTAT, 2012) as new legislation has restricted access to forests and the use of firewood in an attempt to protect natural forests (Ndayambaje and Mohren, 2011).

2.3 Organization of the energy sector and the NDBP intervention

The Ministry of Infrastructure (MININFRA) is responsible for the organization and management of affairs pertaining to the energy sector. The ministry has two Ministers of State, one in charge of transport and the other dealing with energy and water issues (see Annex 1). Specifically, matters pertaining to energy and water are managed by an independent agency within the ministry called the Energy, Water and Sanitation Authority (EWSA). The generation of energy/electricity is largely the responsibility of the public sector with private companies involved in generating energy through small scale (e.g. micro-hydro) projects. Transmission and distribution of energy is the responsibility of EWSA.

In 2005, MININFRA, SNV and GTZ (now GIZ) agreed to create a National Domestic Biogas Programme (NDBP), and signed a 'Tripartite Memorandum of Understanding'. NDBP which is a part of EWSA is responsible for the management and implementation of the domestic biogas sector in Rwanda in collaboration with SNV which provides advisory support. NDBP's implementation plan was launched in late 2006 and in 2008, after training and sensitisation, the programme became operational and digester construction started. Detailed information on the operation of a digester and related drawings and photographs are provided in Annex 2.

The overall objective of the programme is to contribute to poverty reduction, gender equality, health improvement and environmental sustainability via the development of '[…] a commercially viable and environmentally sustainable market-oriented Rwandan biogas sector resulting in the reduction of biomass resource depletion while providing a significant improvement in the quality of life of the families concerned' (Dekelver, 2008). The programme represents an attempt to address a range of issues such as limited availability of firewood and high costs of alternative cooking and lighting options, indoor air pollution caused by the use of firewood for cooking, poor sanitation and hygiene in rural dwellings, gender equality (since women are most likely to benefit from shorter cooking times and less frequent firewood collection) and environmental sustainability through the reduction of pressure on forests. The original objectives of the programme were to: i) install a total of 15,000 family sized, quality biogas plants within the country by the year 2011 ii) to ensure operation of all installed biogas plants iii) to maximize benefits from the operated plants, in particular the use of digester effluent. In terms of specific benefits and returns, a baseline report identified (Huba and Paul, 2007) substantial financial benefits. Although

[14] Rwanda's poo-powered prisons, http://www.bbc.co.uk/news/world-africa-16203507. Accessed on December 12, 2012.

buttressed with caveats, among other financial benefits, annual savings on fuel were expected to be about 21,000 RwF while annual increase in agricultural yield was pegged at about 152,000 RwF.[15] In addition, the program was expected to lead to a reduction in time spent on gathering firewood and cooking, deliver health benefits and enhance access to lighting.

For various reasons, some of which are discussed below, during the course of programme implementation the initially proposed target was adjusted downwards. The chart below summarizes some of the milestones in the implementation of the programme.

2005
MININFRA, SNV and GIZ agree to create a National Domestic Biogas Programme.

2007
A tripartite memorandum of understanding is signed with a target of installing 15,000 digesters by the end of 2011.

2009
NDBP adjusts the target to 5,000 digesters by the end of 2011.

Tumba College of Technology signs an MoU with MININFRA in 2009 to provide training and develop indigenous digester models

Banque Populaire du Rwanda (BPR) becomes an official provider of loans for digesters.

2010
During the Rwandan National Leadership Retreat a new target of 3,000 digesters to be built by the end of 2011 is proposed and accepted.

2011
By end-2011, around 1,700 digesters have been built.

Consistent with a market-based approach, the financing of the programme called for a substantial contribution from beneficiaries and also from MININFRA which has contributed approximately USD 1 million for the installation of demonstration plants in four districts (Government of Rwanda, 2007). Financial data from NDBP are presented in Table 4 and shows the Government of Rwanda's substantial commitment.

Table 4: Budget and funds actually disbursed, in thousands of Euros

Year	2008		2009		2010		2011	
	Budget	Actual	Budget	Actual	Budget	Actual	Budget	Actual
Donors	211	195	124	118	614	805	223	138
Government of Rwanda	68	37	-	20	176	161	667	159
Total	*279*	*232*	*124*	*138*	*790*	*966*	*890*	*297*

Source: NDBP.

The targets set by NDBP are not gender specific (e.g. there is no target in terms of female-headed households), but the programme is expected to contribute to gender equality as digesters may have a larger effect on women's welfare. In particular, since women are primarily responsible for collecting

[15] These figures are based on a 20 year digester life-span and an exchange rate of 553 RwF to 1 USD. Expected financial benefits are based on figures reported in Table 41 of Huba and Paul (2007).

firewood and cooking, and digesters are expected to diminish the effort and time needed to carry out these activities. The improvement in air quality in the kitchen is also more likely to benefit women as they are primarily responsible for cooking and hey spend more time in the kitchen.

A comparison of targets and digesters actually installed reveals a large gap (Table 5 and Table 6). This is perhaps a shortcoming which overshadows the success of the program in other spheres (as shown later).[16]

Table 5: Projected installation of biogas plants

Year	2007	2008	2009	2010	2011	Total
Phase	Preparation phase	Implementation phase				
Number of digesters	150	1,150	2,300	4,200	7,200	15,000

Source: Dekelver, 2008.

Table 6: Installed biogas plants

Year	2007-2009	2010	2011	2012	Total
Number of digesters	366	627	755	699	2,447

Note: Data for 2012 are current up to the end of November.
Source: NDBP.

In hindsight, one may consider that the programme was rather ambitious. The targets were, in part, driven by arguments that Rwanda offered several features that made it a suitable country for a biogas project. These included a conducive policy environment and appropriate climatic conditions, with temperatures that allow digesters to produce gas all-year-round and numerous households interested in the technology.

With regard to the policy issues, the promotion of digesters fits the government's long term plans to reduce dependency on wood as a source of energy (Ministry of Finance and Economic Planning, 2000) and is complemented by other policies, most notably its 'zero grazing' policy and a poverty reduction programme called the 'one cow one family programme' both of which create a conducive environment for the promotion of biogas. With regard to 'zero-grazing', while traditionally, domestic cattle were allowed to graze freely, noting the limited availability of arable and grazing land per head and the environmental damage caused by the animals, the government has enforced a strict zero grazing policy which requires cattle to be kept in enclosed spaces and requires *in situ* feeding. Also zero grazing is common in other countries where land is scarce as it allows more efficient resource use. The policy is applied rigorously and enforced through a fine of USD 50 on cow owners who do not comply. With regard to biogas such a regulation makes it easier to gather the input needed for the digester. The 'one cow one family program' which has been operating since 2006 distributes cows to poor households which has a clear effect on increasing the number of families who own cows (Ntanyoma, 2010).[17]

Indeed, the preliminary feasibility studies indicated that there were 315,000 households with one or more cows in Rwanda (Dekelver et al., 2005). Based on an analysis of the socio-economic conditions of these farmers it was estimated that around 110,000 households had the technical potential to benefit from a

[16] A chart listing various activities and the indicators for successful implementation is provided in Annex 3.

[17] The 'one cow, one family' policy had a target of 257,000 poor households, classified as such by the Ministry of Economic Planning and Finance in 2002, and it had the objectives of i) supporting crop production via the use of manure as a fertilizer, ii) contributing to reduce the phenomenon of soil erosion, and iii) reducing malnutrition through milk consumption.

digester. This number was expected to increase over time as a result of the country's zero grazing and one cow one family programmes.

Despite these expectations uptake has remained lacklustre. Based on our field experience, the single most important reason for the refraction between plans and uptake seems to be linked to prices.[18] The feasibility study, perhaps based on experiences in Asia, since Rwanda was the first domestic biogas experiment in Africa for SNV, pegged the cost of a 6 m^3 digester at about 260,000 RwF, while the actual price turned out to be 800,000 RwF or triple the original estimate.

To appreciate the challenges consider that, on average, after deducting the subsidy of 300,000 RwF households have to contribute between 350,000 ($4m^3$) to 800,000 RwF ($10m^3$) (Table 7). Even though it is possible for owners to lower their financial contribution, by about 140,000 RwF, by contributing building materials, it does not change the requirement that the financial outlay for the smallest digester is about 1.4 times the annual per adult equivalent expenditure of the average household in rural Rwanda.[19] Without the subsidy the costs of the cheapest digester would amount to 2.6 times annual per adult equivalent expenditure. While the programme does offer credit through Banque Populaire du Rwanda (BPR), the loan is limited to a maximum of 300,000 RwF for 3 years at 13 percent interest (versus around 17% in the market), with a monthly repayment of 11,000 RwF. BPR in co-operation with NDBP also sets several conditions in order for a household to obtain a loan. These include i) the farmer has to have a bank account at BPR or another bank ii) the farmer has to own at least 2 cows iii) the bank account has to be active, meaning that at least 2 bank operations should have been executed in the previous year (although, according to the BPR officials, this last prerequisite is not binding). Notwithstanding the initiative to provide affordable credit, given the prices of the digester and the expenditure/income levels of an average Rwandan household it is not clear whether investing in a digester is likely to lead to savings/increased revenue which provide payback within a reasonable time period.

As mentioned in section 2.2, based on Huba and Paul (2007) substantial financial benefits were expected. Annual savings on fuel were expected to be about 21,000 RwF, annual savings on fertilizer about 9,500 RwF while increase in annual agricultural yield was pegged in the range of 152,000 RwF. These expected benefits translate into a very short payback period and whether these benefits have been realized and their effect on payback is an issue that is investigated later on in the report.

Table 7: Size of biodigester, its costs and the subsidy provided (in RwF)

Size of the biodigester plant	Cost of the plant for the user	Subsidy provided
4 cubic metres	350,000	300,000
6 cubic metres	500,000	300,000
8 cubic metres	650,000	300,000
10 cubic metres	800,000	300,000

Source: NDBP (2012).

[18] The EnDev2011 report mentions several challenges that have led to slow progress including lack of autonomy, flexibility and management capacity of the NDBP unit at the Ministry of Infrastructure and the costs/affordability of digesters. Other issues are the high program costs versus the number of digesters that have been set up and concerns about the demand orientation of the program.

[19] Based on a report issued by Rwanda's National Institute of Statistics (2012) per adult equivalent annual consumption in rural Rwanda was 247,240 RWF (including self-consumption). The cost of a 4m3 (10m3) digester is 350,000 (800,000) RWF or 1.4 (3.2) times consumption.

Setting aside viability issues let us examine NDBP's current model. The procedure to apply for the digester involves the NDBP program (central office and field technician), a construction company and a bank (in case the beneficiary applies for a loan). After verifying that an applicant satisfies the criteria needed to obtain a digester (and a loan), NDBP arranges construction through a company which has been trained in digester construction. The digester is covered by a '1 year warranty' and the construction company has to visit the plant 3 times during the first year to ensure proper functioning. The program retains 15,000 RwF which the construction company can access at the end of the 1 year warranty period. Quality checks are also conducted by program field technicians. NDBP has 15 field technicians, one for every two districts. In practice, the final payment is often not a sufficient incentive for companies to conduct the required checks and they delay required visits in order to combine them with other work in the same area. NDBP is aware of the issue and is planning to increase the final payment, providing an extra incentive for the fulfilment of the warranty service by the company. A consequence of the lack of follow-up is that, in some instances, it is possible that a digester is considered as "completed" (on NDBP's list of completed/built digesters) but it may not yet be operational/producing gas.

The programme has several processes to monitor progress. At the central level there is a database containing information on digesters that have been built and on potential applicants. These data along with related expenditures and information on quality control, marketing, research and development, administration and other issues which provide an overall picture of the programme are prepared for EnDev. Since the support of EnDev has come to an end (December 2011), these reports are no longer being produced. Other reporting is done jointly by NDBP and SNV on a yearly basis through an 'assignment review report', a log frame which provides synthetic information on outputs, outcomes and explanation for deviations.

At a more macro level, to implement the programme, NDBP uses a multi-stakeholder approach which brings together several partners. Integrated advisory services are offered by SNV, which has expertise in the biogas sector through its projects in a number of Asian countries.[20] The services offered include policy and institutional development advice, technical design, operational support and fund brokering. SNV support to the biogas programme includes: i) private sector development by supporting the establishment of digester construction companies and building their technical and business capacities ii) technical support by providing quality control and engaging in research and development aspects of the programme iii) market linkages by supporting the building of a biogas market and create links between NDBP and farmers through promotion, marketing and networking iv) access to finance by helping set up a subsidy scheme and a biogas credit scheme through Banque Populaire du Rwanda (BPR). For additional details see Dekelver (2008).

To enhance uptake, the programme establishes local partnerships with diverse stakeholders and there are some successful examples of such an approach. For example a partnership with KWAMP (Kirehe Community-based Watershed Management Project) provided impetus to the programme in Kirehe district, where 186 digesters were installed in the period July 2011-June 2012. Similarly partnerships with NGOs such as Vi-Life and World Vision have contributed to the dissemination of digesters in areas where these organizations are active. The spread and of these partnerships are, on the one hand, an indication of the

[20] SNV has substantial experience in designing and implementing biogas programmes. Its first programme was launched in Nepal in 1989 and since then it has helped established programmes in Vietnam in 2003, Bangladesh and Cambodia in 2006 and in Pakistan and Indonesia in 2009. For more details on SNV's worldwide experience and recent initiatives including its work with the Asian Development Bank to spread biogas use in Asia see http://www.snvworld.org/en/sectors/renewable-energy/about-us/snv-energy/domestic-biogas/snv-and-domestic-biogas

achievements of the program in putting in practice a multi-stakeholder approach, on the other hand, given the range of partners it may not always be possible to maintain coherence. For instance, in the partnership with KWAMP, apparently households received a double subsidy. Thus, while KWAMP has supported the objective of installing digesters, it may have undermined the market-based approach. Since the extra subsidy provided by KWAMP is temporary and will be discontinued in 2013, it might have a negative effect on digester uptake in the longer run.

Other partners include Tumba Technical College located in the country's Northern Province. The college runs a renewable energy program including a biogas component and has trained approximately 200 technicians. Training has already been provided to 4 batches of students and is integrated into the college's regular curriculum which bodes well for the sustainability of this aspect of the program. Training activities have also been directed to construction companies and 94 companies have been trained by the programme in digester construction. According to NDBP data, in June 2012, 42 of these companies were still active.[21] Other forms of training, beside construction, are provided by NDBP and SNV and focus on promotion and marketing of digesters.

An interesting and related technical development is that Tumba Technical College has also been working on the design of new digester models which are adapted to local conditions, both, in terms of construction materials and design. At the moment the programme relies on a digester adapted from Nepal (the GGC model), while models Rwanda 1, 2, 3 have been developed specifically for the Rwandese market. These use less concrete and rely on burnt bricks.[22] These innovations are expected to lead to a substantial reduction in prices and were expected to be launched by the end of 2012.[23]

At the level of the Rwandese government, given the importance of the biogas sector, there is pressure for NDBP and for local governments to deliver in terms of installing digesters and progress is discussed in leadership retreats which are periodic meeting of concerned officials with the President. Furthermore, targets in terms of constructed digesters are included in (some of) the districts performance contracts signed by the President and the administrative units (MININFRA and local governments).[24]

Overall, despite the Government's support to the programme and some favourable local conditions, NDBP faces multiple challenges which have been translated into a lower than expected number of households purchasing digesters. At the end of 2011, due to limited uptake, EnDev support has been discontinued. However, the government remains committed as confirmed by its willingness to provide financial support and the same level of subsidy despite the withdrawal of donor support. [25]

[21] Some of the companies that were trained were start-up firms while others were existing firms. The reasons for the decline in the number of active firms from 94 to 42 are not clear. Acording to NDBP the firms may have shut down due to lack of business. Based on previous work (see www.snvworld.org/.../i_love_biogas_it_is_a_profitable_business.pdf) it seems that while there are number of active firms the business is dominated by a few companies. Of the 741 digesters built between July 2010 and June 2011, 55 percent were built by 7 of the 53 companies operating at that time. While 20 of these 53 accounted for about 8 percent of the digesters (Binamungu et al. 2011). The decline in the number of active firms from 53 in June 2011 to 42 in June 2012 displays that while a number of firms have been trained the existing demand for digesters is not enough to support so many firms. Details on firm turnover and reasons for their success or failure are provided in Annex 6.

[22] During the initial years of the program the use of burnt bricks was forbidden as the Government had banned the use of firewood for brick manufacturing and thus more expensive concrete had to be used for the construction of digesters. This restriction has now been eased.

[23] According to SNV Rwanda, depending on the digester size, the redesigned digester models are 14.6 percent (for the $4m^3$ model) to 24.8 percent cheaper (for the $10m^3$) as compared to the existing models.

[24] On the performance contracts, see ODI (2012).

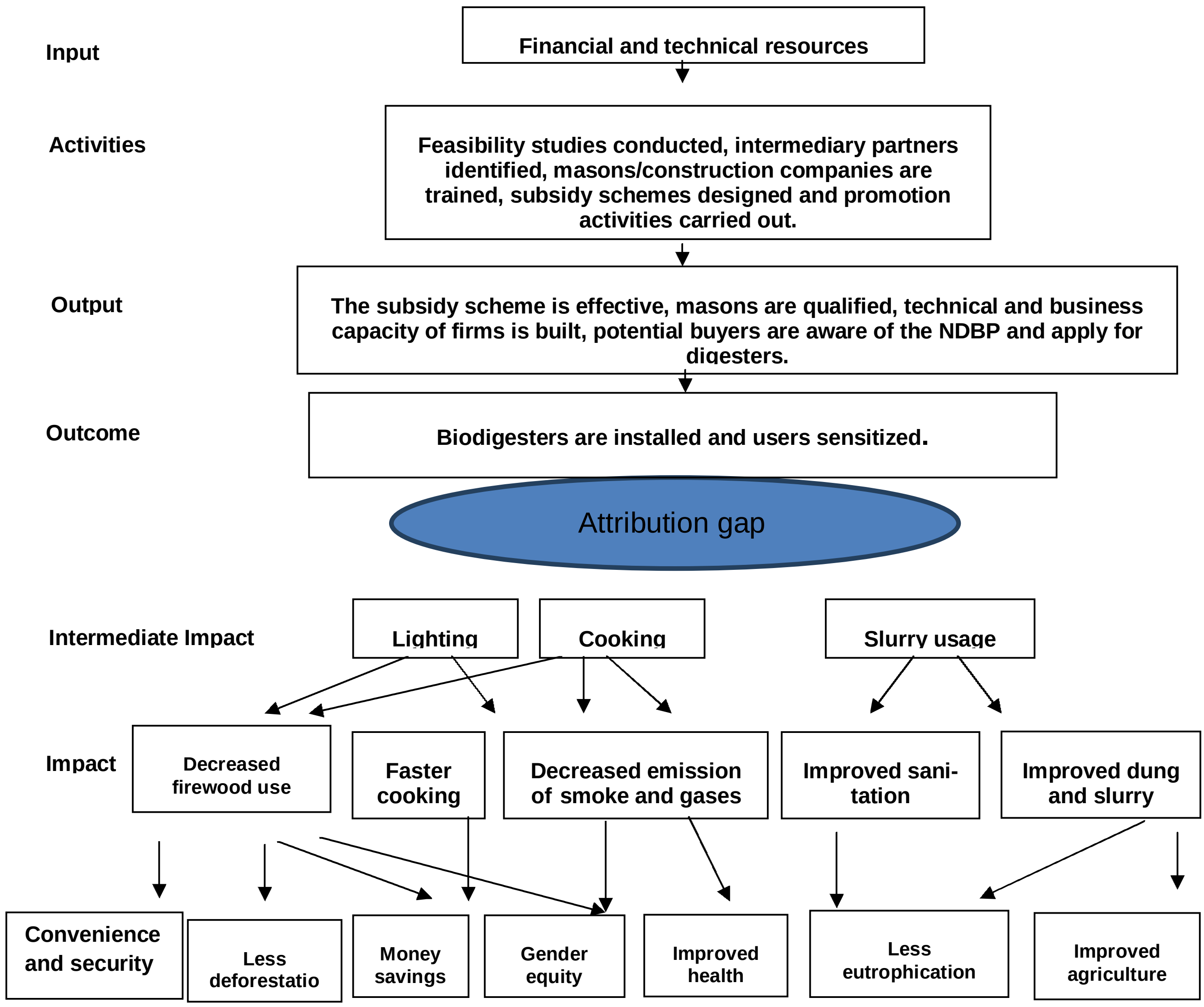
3. Methodology/Evaluation Approach

3.1. Evaluation objective

The main aim of the evaluation is to identify the impact of access to biogas provided through the NDBP programme on a range of household level outcomes. A stylized result chain linking inputs and activities to outputs and outcomes and subsequently to impacts is provided in the figure below:

[25] Although EnDev support has been discontinued, SNV continues to provide technical, management, promotion and business support to the NDBP program. Technical support includes the development of smaller size biodigesters, the study of alternative designs and the exploration of additional packages to be sold together with digesters (e.g. solar kits). Management support includes collaboration in terms of drafting proposals for a second phase of the NDBP and brokering with potential funders. Promotional activities include sensitization of farmers, production of promotional material and training of technicians. Business support includes activities carried out to support construction companies (e.g. on financial management and accounting) and loan providers (BPR branches and exploring new opportunities with Savings and Credit Co-operatives).

Figure 3: The NDBP results chain



Source: Own illustration.

The precise questions that this evaluation focuses on, and which corresponds to section 2.3 of the terms of reference, are provided below:

Installation and use (prior to attribution gap)

- Who (gender specific) in the household has made the decision to install the biodigester?
- Did the household apply for a bank loan? For which percentage of the total investment costs?
- Has the household been properly informed about how to use the biodigester (e.g. plant initial feeding, presence of user manual)?
- To what extent have installed biogas plants actually been used (gas production)? If not, why?
- What is the digester feed stock?
- How much is saved in total (per week or month) on ‘traditional’ energy sources (candles, kerosene, and firewood)? How have expenditures for energy changed?
- Which expenditures does the household reduce in order to finance the investment into the digester?
- How reliable is the gas supply?

Intermediate impact

- For what purposes is biogas used (cooking, lighting, other)?
- Has there been any change in time/ workload, disaggregated by gender?
- To what extent has sanitation improved?
- Does the household use the slurry as fertiliser?

Impact

- To what extent do activities during evening hours change due to improved lighting usage? Have study hours/ reading time of children changed?
- For what purposes is the time saved been used, disaggregated by gender?
- To what extent has indoor air pollution been reduced (perception of users only)?
- To what extent have health conditions (in particular respiratory illnesses) changed, specifically among women and children?
- To what extent has comfort/ convenience changed, disaggregated by gender? What monetary value do households attribute to this increased convenience?
- Has the availability of biogas triggered new economic activities? Which ones?
- What (if any) are the un-intended impacts?
- How many households (as share of the sample population) keep on using traditional stoves?
- How have cooking and lighting habits changed due to the use of biogas?
- Based on secondary sources, what is the effect of digester slurry on agriculture (use and sale of fertiliser, expenditure on fertiliser, frequency of manure collection, crop yields)?
- What have been the changes in farming, in particular livestock management (free roaming versus zero-grazing, number of livestock, etc.)?
- What have been the changes in farming systems, in particular livestock management (free roaming versus zero-grazing, number of livestock, etc.)?
  How have the benefits been distributed among households in different income groups?
- Have additional jobs been created in the biogas business sector (contractors, masons, input supply), disaggregated by gender?

3.2. Identifying impact

As mentioned in the introduction, the evaluation is based on cross-section data and on a comparison between households that are beneficiaries of the biogas programme (treatment group) and households that are not (control group). The key evaluation challenge is to identify the extent to which differences in the impact indicators between these two groups may be attributed to the programme.

There are several reasons why a straightforward comparison of differences in mean outcomes between these two groups and attribution of the differences to the NDPB programme may be naive. First, there is an element of self-selection, as households need to take the initiative to apply. This decision may depend on the financial commitment needed and the potential future benefits of installing a digester. Hence, the (latent) ability and productivity of a household, their risk taking ability, their ideas of modernity and other unobserved factors may affect the probability of applying. At the same time, these factors may also affect the outcomes of interest. Second, conditional on application, programme beneficiaries are not selected at random but need to fulfil certain criteria, the most important of these is the condition that a selected household must have at least two cows. In addition to this observed criteria there may be other selection criteria that determine beneficiary status but which cannot be observed by a researcher. In short, not accounting for factors (observed and unobserved) that determine beneficiary status and which may also be correlated with outcomes is likely to lead to misleading programme effects.

In order to provide a credible assessment based on cross-section data and a comparison of treatment and control groups it is important to ensure that the control group is, on average, in terms of traits that are not responsive to the intervention, identical to the treatment group. Three steps have been taken to enhance comparability. First, in order to deal with self-selection and to ensure comparability of unobserved traits which may drive the demand for a digester we chose a set of control households from a list classified as potential applicants by NDBP. Second, from this universe of control households, after verifying whether the potential applicants were still in the applicant stage, we chose households that fulfilled the key verifiable condition (having at least two cows) needed to obtain a bio digester.[26] Third, as far as possible control households were drawn from the same district and the same village as the treated households.

Given the manner in which the control group has been designed, in principle, after verifying whether the two groups are, on average, statistically equivalent, it is arguably credible to attribute mean differences in outcomes of interest to the intervention. While this seems attractive, based on interactions with households it turned out that the list of potential applicants may include households who now have little or no interest in biogas. This clearly hampers our ability to control for unobserved traits that may determine uptake and outcomes. In addition, it was not always possible to obtain control households from the same village.

To deal, at least partially, with these concerns we have gathered information on a wide range of characteristics that may influence digester uptake and use linear multiple regression analysis to control for various factors that may have a confounding effect on the outcomes of interest. In

[26] The two cow requirement is related to the manure required to generate sufficient biogas. In practice, this requirement was not always satisfied. In our sample data we find that in the case of both owners and potential applicants the requirement was not satisfied in about 5-6 percent of the cases.

addition, to obtain a better control group and to relax the assumption of a linear relationship between the intervention and outcomes, we provide estimates based on propensity score matching (PSM). Using this approach, each individual in the treatment group is matched to observationally similar applicants (control group) in order to reduce observable heterogeneity between treatment and control groups. Thereafter, differences in means of the outcomes of interest between the treated and matched controls are computed to obtain the average treatment effect on the treated (ATT). Provided that digester ownership is driven only by observed variables, the ATT provides an unbiased estimate of the effect of the programme on outcomes.[27]

Finally, a caveat, despite the use of the three approaches outlined here, the possibility that unobserved characteristics differ across the treatment and control group and influence outcomes cannot be ruled out. However, we expect that due to the manner in which the control group has been formed and the ability to control for a wide range of observed characteristics, we are able to provide credible estimates of the effect of the NDBP programme.

4. Data

Data and information needed to respond to the terms of reference have been gathered from a range of sources. The quantitative part of the evaluation is based on a survey of 600 households that was conducted in June-July 2012. The qualitative information base draws upon existing studies and documents, open and semi-structured interviews with project/programme staff, (potential) beneficiaries, various stakeholders (see details below) and a structured survey canvassed in 20 villages. This section of the report provides details on the data gathering process for both the quantitative and qualitative information bases.

4.1. Survey tools and implementation

Prior to field work in May 2012, two survey instruments, a household and village questionnaire, were designed by ISS/RWI. The household questionnaire was designed to gather self-reported information on a wide-range of socio-economic aspects and in particular on cooking behaviour, energy use and energy related expenses (see Annex). Given the purpose of the evaluation the questionnaire contained a detailed section on the reasons for (not) purchasing a digester, financing of the digester, its functioning and various other aspects. The village questionnaires were designed to gather information on the creation of new economic activities and job creation which may have occurred due to the development of the biogas sector.

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[27] In the current application we match the treatment and control group on the basis of the observable characteristics reported in Table 12. The approach is based on the (conditional independence) assumption that digester ownership is driven only by observed variables.

Let *DO* indicate digester ownership. Propensity scores, that is, $Prob(DO_i = 1 | X_i)$, are obtained from a logit/probit regression of digester ownership on observed characteristics (X_i). The average treatment effect on the treated (ATT) when *N* digester owners are matched to applicants (*A*) may be written as,

$$ATT = \frac{1}{N} \sum_{i=1}^{N} (Y_i^{DO} - \sum_{j=1}^{C} W_{ij} Y_j^{A}).$$

Y_i indicates the outcome for each of the different groups and W_{ij} are the weights that are used to calculate the counterfactual outcome for each digester owner. In this report the ATT is estimated using five nearest-neighbours and estimates are restricted to the region of common support. In the case of the five-nearest neighbours each of the controls (C) is equally weighted (1/5) and C = 5.

Drafts of the questionnaire were shared with SNV NL, SNV Rwanda and our Kigali-based research partner, Inclusive Business and Consultancy (IB&C).[28] Based on their inputs the questionnaires were adjusted prior to the mission. During the mission, the revised questionnaires were shared and discussed with NDBP and SNV Rwanda and refined in order to better reflect the context and the manner in which the project operates. Some questions were removed – for example, biogas is not used for water heaters, while additional options were added for some questions (sources of microfinance; reasons for installing a digester). Since the instrument had been discussed prior to the mission no major adjustments were needed.

After finalization the questionnaires were translated into the local language (Kinyarwanda) and along with IB&C, the ISS/RWI researchers organised a 3-day enumerator training programme. As part of the training staff from SNV and from NDBP provided information on the NDBP program and examined the local language version of the survey instruments.[29] During the training each of the survey questions were explained, and doubts and concerns raised by the 16 enumerators discussed and clarified. Both the English and the local language versions of each question were examined in order to ensure consistency. Thereafter, the enumerators conducted role-plays to increase their familiarity with the questionnaire. Confusion and queries arising from this exercise were noted and questionnaires were fine-tuned to weed out inconsistencies and mistakes.

The training and role-playing was followed by a one-day pre-test. For the pre-test, a dozen pre-selected households, both users and non-users living in Kigali district were interviewed. The enumerators worked in pairs and each pair of enumerators interviewed 2 households. The one-day pre-test provided an opportunity to test the skills of the enumerators and to iron out remaining problems and also provided information on the time taken to complete the questionnaire (about 2 to 3 hours). After the pre-test, the 12 completed questionnaires were examined, errors were identified and steps were taken to guard against such mistakes.

During the mission an excel data entry template for both the household and village questionnaires was designed and three individuals received training on data entry. Data from the 12 completed pre-test questionnaires was entered. It took about 40 minutes to enter data from each questionnaire.

The household survey was canvassed in the selected areas (see following section) during the period June to July 2012. 16 enumerators divided into two groups, one supervised by an intern from RWI (Ms. Rebecca Meyer) and another team supervised by Mr. Ancient of IB&C gathered the data.[30] After data collection, 8 enumerators entered the data. The village questionnaires were canvassed by 2 enumerators in November 2012.

A first version of the household level data was sent to ISS/RWI researchers at the end of July 2012 while a first round of the village data was sent in early November 2012. After a number of quality

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[28] IB&C has substantial data collecting experience and has also worked with ISS/RWI on the evaluation of the Energy Access Roll Out Programme (see Bedi *et al.*, 2012). IB&C was responsible for data collection and steps related to the process such as recruitment and training of enumerators and data-entry operators.

[29] The emphasis was on ensuring consistency between specific words used in the questionnaire and words used by NDBP/SNV. For example, in the context of learning how to use and maintain a digester the word 'training' was substituted by 'instruction process'.

[30] Ms. Meyer stayed in Rwanda during the data gathering process. Her main tasks were to supervise the survey and to ensure quality control in terms of data gathering and data entry.

checks and revision, a final version of the household data was handed over to ISS/RWI at the end of October 2012 and a final version of the village data was handed over in mid-November 2012.

4.2. Sampling method

Household

The NDBP program provided the researchers with a database that contained information on two sets of households (I) a set of households who have applied for a digester, who have received a subsidy and the construction of a digester has been completed (ii) a set of households who have shown an interest (potential applicants) in obtaining a digester, but who have not yet formally applied for a digester and who according to NDBP don't yet have a digester. The database also contains information on the dates of application (in most cases), the geographical location of the households and (mobile) telephone numbers. Telephone numbers are available for 91 percent of the households in list (I) and 91 percent of households in list (ii).[31]

Given the budget limitations the overall sample size was set at 600 households, divided into 305 treated and 295 control households. Power calculations (setting alpha = 0.05 and beta = 0.8) suggest that this sample size is sufficient to detect reasonable effect sizes (standardized effect size of 0.25) for the main outcome variables (firewood/charcoal consumption, energy expenditures and time use). The sampling strategy was developed on the basis of the two lists of households provided by NDBP. The list of households with completed digesters consisted of 1,802 households while the list of potential applicants included 3,104 households.

From the list of households with completed digesters we included those households that have had a digester completed at least 6 months prior to the survey (1,722 households), that is, up to December 2011.[32] This allows time for the possibility that there are delays between completion and commissioning of the digester and it allows time for developing experience in terms of operating a digester and for the effects of bio-gas to occur. Subsequently stratified (at the district) random sampling with probability (of sample inclusion) proportional to the number of treated households per district was used to obtain a list of 305 treated households. In order to allow for cases where a selected treated household could not be found or refused to answer, replacement households were identified. Nationwide coverage of the NDBP is a crucial feature of the program and in order to ensure that the sample reflects this feature we opted for the use of stratification based on geographical location.

[31] According to Rwanda's Utilities Regulatory Agency (RURA), mobile phone penetration rate in Rwanda was close to 42 percent in June 2012. The higher mobile phone penetration rate for households who show an interest in owing a digester and have two cows is not surprising given their higher socio-economic status as compared to an average household in Rwanda.

[32] All the treated households included in the sample come from the NDBP lists. There are several categories of individuals with completed digesters. These include those who are (i) Classified in the after sales service group (guarantee period has expired) (ii) Operational and the guarantee period has not yet expired (iii) Completed digesters which means that digesters are completed and *maybe* operational but are *not* classified as operational as the construction company has not conducted a final check, or a field technician has not approved the construction, or the digester is not yet connected to the kitchen or the household does not yet have a biogas stove. We have allowed for a gap of at least 6 months and included households in category (iii) as they face financial liabilities even if the digester is not classified as operational.

The number of households with a completed digester plant, the share of treated households and the number of treated households sampled, disaggregated by provinces, is presented in Table 8. Table 9 provides the same information disaggregated at the district level.

Table 8: Distribution of treated and control households, at the province level

Province	Number of treated households (pop.)	Share of treated households in each province	Number of treated households sampled	Number of control households sampled
Eastern province	604	35.08	112	103
Kigali city	166	9.64	25	27
Northern province	478	27.76	85	82
Southern province	279	16.20	50	48
Western province	195	11.32	33	35
Total	*1722*	*100*	*305*	*295*

Source: Own elaboration.

Table 9: Distribution of treated and control households, at the district level

Province	District	Number of treated households (pop.)	Share of treated households in the total treated population	Number of treated households sampled	Number of control households sampled
Eastern province	Bugesera	62	10.26	11	12
	Gatsibo	62	10.26	11	10
	Kayonza	90	14.90	15	15
	Kirehe	131	21.69	24	16
	Ngoma	100	16.56	17	22
	Nyagatare	73	12.09	14	13
	Rwamagana	86	14.24	20	15
Kigali city	Gasabo	116	69.88	19	20
	Kicukiro	34	20.48	4	5
	Nyarugenge	16	9.64	2	2
Northern province	Burera	122	25.52	23	24
	Gakenke	46	9.62	9	7
	Gicumbi	117	24.48	20	20
	Musanze	108	22.59	19	19
	Rulindo	85	17.78	14	12
Southern province	Gisagara	22	7.89	4	4
	Huye	21	7.53	4	4
	Kamonyi	49	17.56	9	9
	Muhanga	39	13.98	8	6
	Nyamagabe	31	11.11	5	5
	Nyanza	35	12.54	6	6
	Nyaruguru	16	5.73	3	3
	Ruhango	66	23.66	11	11
Western province	Karongi	26	13.33	5	5
	Ngororero	13	6.67	2	2
	Nyabihu	35	17.95	6	6
	Nyamasheke	32	16.41	6	6
	Rubavu	44	22.56	7	9
	Rusizi	25	12.82	4	4
	Rutsiro	20	10.26	3	3

Source: Own elaboration.

To determine the control group we used the list of potential applicant households provided by NDBP. The list of potential control households living in the same geographical area (village) as the treated households was identified, ordered randomly, and distributed to the enumerators. The probability of inclusion is proportional to the number of treated households in a district, i.e., for each treated household in the geographical area one control household has been drawn.

Before interviewing a potential control household, enumerators were asked to ensure that these pre-selected control households indeed did not have a digester and that they fulfilled the necessary conditions to receive a digester. Together with NDBP it was agreed that this would be verified through phone calls with enumerators calling the potential control household and asking:

i) Do you have a constructed digester (even if without pipes)? If the answer is yes, this household is excluded and the enumerator needs to contact the next control household on the list.

ii) Are you already incurring any digester related expenditure (e.g. loan, payment to the construction company, payment to buy materials)? If the answer is yes, this household is excluded and the enumerator needs to contact the next control household on the list.

These two questions were needed in order to verify whether the potential applicants had not yet started using a digester and/or paying fees related to the digester.

iii) How many cows do you currently have? The most important condition in order to obtain a digester is ownership/possession of at least two cows. This check was conducted in order to ensure that the control group satisfies the key verifiable condition needed to obtain a digester.

To reiterate, the 295 control households are potential applicants, they should have at least two cows, they are drawn from the district and in principle from the same village as the treated households (e.g., 11 control households should be interviewed in Bugesera district, 11 in Gatsibo and so on). As shown in Table 8 and Table 9 while there are some deviations, for the most part there are an equal number of treated and control households from a district. This proximity approach ensures that both treated and control households are from the same geographical area and since agriculture is the main activity, they are exposed to similar external factors (e.g. climate). Over all, drawing a control group on the basis of the process outlined above should facilitate comparisons.

Villages (umudugudus)

To assess the wider economic impact of the development of the biogas sector, village level information has been gathered. Since these questions are related to the creation of new economic activities which are more likely to occur in areas where there is a higher concentration of digesters we decided to focus on such villages. Based on data from NDBP there are 40 villages with five or more digesters. We conducted village level surveys in 20 of these villages spread over four of the country's five provinces (see Table 10). In these 20 selected villages, the number of digesters ranges from 5 to 19 (nationally, the maximum number of digesters in a village is 19). The 20 selected villages are located in the provinces of Kigali City (6 villages), South (5), North (2) and East districts (7).

Table 10: Selected villages for the community survey

District	Village	Number of digesters
Kigali City	Rebero	19
	Ndatwa	10
	Cyeru	7
	Karenge	7
	Rubona	7
	Kigabiro	5
South	Nyabisindu	7
	Gasharu	7
	Nyagasozi	7
	Ngoma	6
	Taba	5
North	Karambi	10
	Bikamba	6
East	Rugarama	14
	Munini	12
	Mubuga	12
	Byimana	10
	Indatwa	9
	Rurama	9
	Kabuga	6

Source: Own elaboration.

4.3. Qualitative data and desk research

In order to respond to the issues outlined in the sub-section titled, *Problems and context*, in section 2.1 of the ToR the main approach has been to draw on secondary information. For the sub-sections titled *Policy Relevance* and *Outcome at National Level* as well as for the section 2.2, sub-sections titled *Input* and *Output* we rely on key informant interviews, semi-structured interviews with different sets of households and information gathered from the village-level instrument. In some more detail, the following steps have been undertaken:

(i) First, based on the existing secondary information and the issues to be analysed a list of potential stakeholders that should be visited was drafted:

- SNV in Kigali, GIZ (International organizations supporting the project)
- Representatives from the National Domestic Biogas Programme in Kigali
- NDBP - Field technicians responsible for implementing and monitoring the programme
- Representatives from the schools doing research on adjusting the digester to local conditions (Tumba College of Technology)
- Representatives from the Higher Institute of Agriculture and Animal Husbandry who are working on the use of bio-slurry as a fertiliser
- Representatives from Banque Populaire du Rwanda which provides credit
- Representatives from companies that are installing the digesters

(ii) Semi-structured interviews were conducted with each of these key informants. The questions raised during the interview closely followed the kind of information needed to respond to the ToR. For instance, after a brief introduction, the discussion during the interviews followed the list of questions set out in the relevant parts of section 2.1 and 2.2. Responses were noted, and summaries of each interview are readily available.

The table below (Table 11) provides a list of the organizations and individuals with whom interviews were conducted.

Table 11: List and role of the interviewed organizations

Name of the organization / institution – Location	Persons interviewed
SNV – Kigali	• Eric van Waveren, Director • Elvine Binamungu – Renewable Energy Advisor • Anaclet Ndahimana – Renewable Energy Advisor • Dominique Owekisa – Financial and Business Development Services
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) – Kigali	• Benjamin Attigah
Energy, Water and Sanitation Authority	• Charles Kanyamihigo – Director Energy Development Division • Gaspard Nkurikiyumukiza – Head Renewable Energies
National Domestic Biogas Program (NDBP) – Kigali	• Alphonse Bizimana – Finance and Administration in NDBP • Timothy Kayumba – Biogas Programme / Projects Coordinator • Alain Patiene Niyibizi – Quality Control Officer in NDBP
Dutch Embassy in Rwanda –Kigali	• Fred Smiet – Premier Secretaire d'Affaires Regionales
Tumba College of Technology – Rulindo – Northern Province	• Pascal Gatabazi – Principal
Higher Institute of Agriculture and Animal Husbandry – Musanze – Northern Province	• Charles Karemangingo – Rector
Field technician – Musanze – Northern Province	• Niyindagiye
Field technician – Ngoma – Eastern Province	• Hemabre
Banque Populaire du Rwanda Ltd– Ngoma – Eastern Province	• Janvier Sebanani – Agri Commercial Officer of the Ngoma Branch
Kirehe Community Based Watershed Management Project (KWAMP) – Luseke – Eastern Province	• Joseph Nsabimana – Kwamp Representative • Jean de Dieu Tinasyona, Mayor of economic affairs
Kirehe Community Based Watershed Management Project (KWAMP) – Kigali	• Casasira Janvier – Director
Construction company	• Karim –Owner
World Vision – Kigali	• George Gitou – Director

Source: Own elaboration.

During the mission, in addition to these key informant interviews with whom semi-structured interviews were conducted, semi-structured interviews were also conducted with a set of 6 households – 3 treatment (user, constructed and not completed, construction just started) and 3 control (just received loans to purchase a digester). These households were randomly chosen from villages located within a 2 hour drive from Kigali and based on the lists supplied by NDBP. These households were selected from different provinces (Kigali and Eastern province) in order to capture variation across locations.

After the mission and during the collection of the household data an additional set of semi-structured interviews were conducted with about 12 households (evenly split between treatment and control) in the Western, Northern and Southern provinces. The aim of this exercise was to engage with households in a manner which allowed them to respond to questions without being constrained by the boundaries of a formal survey instrument.

4.4. Data quality

The household questionnaire covered a number of areas and given the level of detail requested from each household took between 2 to 3 hours to complete although increasing familiarity did lead to a reduction in the time required to complete the form. The overall quality of the survey data varies across sections and also in terms of the level of detail that we were able to gather for each individual. The paragraphs below provide an assessment of the quality of the information.

The 600 surveyed households consist of 3,808 members. Information on demographic composition of the household (household size, gender, age, household composition) is complete and the number of missing values was negligible. Similarly information on the education and occupation of the household head is complete.[33] While we have complete information on education and occupation for all household members over 6, only in 35 percent of households did an individual identify himself/herself as the spouse of the head. This seems unusual and attempts to resolve this have not been successful and while we do work with the data that we have on spouses, this is a limitation. Information on household assets such as house ownership, material of roof, floor and on the presence of household consumer durables is complete.

Information pertaining to a household's agricultural activities and livestock ownership is well covered by the survey. Depending on the variable, at most, the number of missing observations for variables such as amount of land owned, crops grown, crop output, amount sold and total revenue generated through agricultural activities is 3 percent. With regard to the number of cows, although the requirement is that all households should have two or more cows this is not always met as about 5-6 percent of households had less than 2 cows and in the case of 15 households (2.5 percent) zero cows. This is possible as some digester owners claim that they are able to buy cow dung from others and may not necessarily be a data concern. In any case the number of cows below the two cow threshold is not different for treatment and control households.

The detailed module on digesters (about 50 questions) contains comprehensive information and while there are some missing values (no information on plant size for 3 households; 20 households were not aware of the total cost of the plant) there appear to be no major reasons for concern. Similarly, questions pertaining to energy use and expenditure and cooking and lighting patterns are quite well covered. There are missing values for some of these questions - ranging between 1 to 6

[33] Information on age was missing for two household heads and on years of educational attainment for one household head.

percent depending on the variable in question - but this is unlikely to have a substantial bearing on the analysis.[34]

Information on health conditions is well-covered as is information on the time-use variables (at most, 5 percent missing values). Information on expenditure was canvassed through a series of questions consisting of 16 categories. Enumerators were free to choose whether to record this information on a weekly, monthly or yearly basis in order to allow the respondent to choose the most convenient recall period. Given our past experience on the EARP project extra attention was paid to these expenditure related variables and several interactions took place between ISS/RWI and IB&C to keep these missing values (essentially "don't know") to a minimum. This is important as incomplete information on any one of the expenditure categories makes it difficult to compute total expenditure and limits the use of that household in the analysis. While we were able to minimize this source of concern we were unable to eliminate it. For a key expenditure item, food, we were unable to get complete information on about 7 percent of households (41). Our examination of the data shows that there is no systematic relationship between not being able to provide information on this variable and other household traits.[35] For the moment, instead of trying to "recover" these observations by using a zero-order correction (replacing the missing values with means of the variable) or any other imputation process, we have dropped them from the analysis. This hampers precision but should not affect the consistency of the estimates.

The village level questionnaires were directed to the village chiefs. As compared to the household data the questionnaire is relatively short and straightforward. The data is complete and there are no missing values.

Two additional points - to ensure transparency, throughout the analysis we provide information on the number of observations on which a test statistic or a regression estimate is based. Second, as an additional check on data quality we provide, in the next section, a brief assessment of the sample profile in the biogas sample data as compared to data from other surveys.

5. Impact assessment

We begin our assessment of the NDBP by first examining whether the treated and control groups are indeed comparable (section 5.1). This is followed by a description of various issues related to installation and use of biogas such as reliability of gas supply, decision-making related to digester purchase and other related questions (section 5.2). Thereafter, as the first step towards identifying the impact we examine differences in means of various outcomes between treatment and control groups. Section 5.3 deals with the use of bio-slurry and agricultural activities, section 5.4 deals with energy use, section 5.5 and 5.6 with health outcomes and time use, respectively. Section 5.7 provides econometric estimates while section 5.8 deals with village-level effects.

[34] For instance information on number of people for whom meals are prepared has not been answered by 17 percent of the households in the case of breakfast and 5 percent in the case of lunch. In general, the missing values ranged between 1 to 6 percent depending on the variable in question.

[35] An ordinary least squares regression of the probability of providing information on food expenditure on a range of socio-demographic variables is jointly statistically insignificant at conventional levels indicating that there are no systematic patterns between not being able to provide information and household traits.

5.1. Sample profile and comparability of digester owners and potential applicants

To provide a profile of the sample at hand and more importantly to examine whether the two groups are similar in terms of their observed characteristics, Table 12 provides information on a range of socio-demographic characteristics.

In terms of the overall profile, a typical household in the sample is headed by a 48 year old male (84 percent) and the household consists of about 6 members. On average, a household head has about 7 years of schooling while spouses tend to be a little less educated (6 years). Almost all children in the age group 7-12 attend school. In terms of indicators of household wealth, almost all the households in the sample own their homes and a majority of their houses are made of brick. Not surprisingly, given that these are pre-requisites which need to be satisfied to own a digester, 95 of the households have a bank account and 95 percent also own 2 or more cows. Per capita annual expenditure (excluding self-consumption) is 282,117 Rwandan francs (RwF).

Comparisons with the nation-wide and nationally representative Demographic and Health Survey (DHS) conducted in 2010 show that while the sample at hand (henceforth biogas study (BGS) sample) is similar to an average household in the DHS in terms of household size, age of head of household and the share of households owning land; there are marked differences in characteristics indicating household wealth. Almost all households in the BGS sample own cattle and have a bank account while the corresponding numbers in the DHS are 30 percent and 29 percent, respectively. A household head in the BGS sample is twice as educated as a household head in the DHS (7.5 versus 3.4). In terms of per capita expenditure, in 2011, at current prices the mean yearly consumption per adult equivalent in rural Rwanda was 247,420 RwF, including self-consumption, and about 207,652 excluding self-consumption or about 27 percent less as compared to households in our sample.[36] The main point is that households in our sample are somewhat more prosperous as compared to an average rural household in the country.

Turning to a comparison between digester owners and potential applicants we see that they are well matched in terms of the key criteria used to determine eligibility – cow ownership (Table 12) and number of cows (Table 13). On both criteria, differences between the two groups are statistically insignificant.

In terms of other characteristics as well, the two groups seem to be well-matched. In both cases the proportion of household heads, age of household head, household size and demographic composition and expenditure are statistically the same. Digester owners seem to be somewhat more educated (about one year more), and there are differences in the occupational distribution of the spouses of the household head.[37] To push the analysis further, Table 14 provides information on land ownership and agricultural activities. Digester owning households own about 0.5 hectares more of land but on other attributes differences between digester owners and potential applicants is statistically insignificant.[38]

[36] See http://eeas.europa.eu/delegations/rwanda/documents/press_corner/news/poverty_report_en.pdf

[37] It is possible that the occupational distribution of the spouse is influenced by access to a digester. This issue is examined later on in the text.

[38] These differences imply that estimates of the effect of digester ownership need to control for differences in education and household assets (land). This issue is discussed further on in the text.

Table 12: Household's characteristics of digester owners and potential applicants

	Mean total (standard deviation)	Digester owners (standard deviation)	Potential applicants (standard deviation)	H_0: $X_{DO} = X_{PA}$ *p*-values
HH (household head) is male (in percent)	83.7 (0.37)	84.6 (0.36)	82.7 (0.38)	0.53
Age of the head of the household	48.3 (11.0)	48.9 (11.5)	47.7 (10.5)	0.17
Household size	6.3 (2. 6)	6.5 (2.7)	6.2 (2.5)	0.25
Household composition (in percent)				
Share children 0-15 years	41.1	39.6	42.7	0.44
Share elderly 65+	2.4	3.2	1.5	0.17
Number of years of schooling of HH	7.5 (4.13)	8.01 (4.33)	7.0 (3.86)	0.00***
Number of years of schooling of spouse of HH[a]	6.4 (3.03)	6.3 (3.14)	6.4 (2.94)	0.97
Share of children aged 7-12 attending school	92.5	91.7	93.3	0.68
Main occupation of the HH (in percent)				
Farmer	54.3	53.1	56.0	0.54
Public employee	10.2	10.5	9.6	0.78
Other independent activity	21.5	22.6	20.1	0.49
Other dependent activity	8.3	8.2	8.5	0.90
Other	5.7	5.6	5.8	0.92
Main occupation of the spouse of HH (in percent)[a]				
Farmer	73.8	68	80	0.06*
Public employee	12.4	15	9	0.26
Other independent activity	7.4	12	3	0.01***
Other dependent activity	1.5	0	3	0.08*
Other	4.9	5	5	0.97
House ownership (in percent)	99.7	100	99.3	0.14
Material of walls (in percent)				
Stone	2.5	3.3	1.7	0.21
Mud	3.3	2.0	4.7	0.06*
Brick	71.0	70.0	71.2	0.30
Cement	10.0	12.9	8.5	0.08*
Wood	13.2	11.8	13.9	0.88
Household has a bank account	94.7 (0.22)	96.4 (0.18)	92.9 (0.25)	0.06*
Households has 2 or more cows (in percent)	94.5 (22.81)	93.77 (24.20)	95.2 (21.29)	0.42
Per capita yearly expenditure (in RwF)[b]	282,117 (426,954)	291,177 (363,308)	273,026 (482,968)	0.61
Number of observations	600	305	295	

Notes: The last column of the tables tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. [a] The statistics on the spouse of the head of the household (schooling and occupation) include only 188 households (93 digester owners and 95 potential applicants). [b] Statistics on per capita yearly expenditure include 559 households (280 digester owners and 279 potential applicants).

Source: Biodigester Rwanda dataset 2012.

Table 13: Livestock ownership

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Cow (milking, non-milking and calves)	5.6	4.9	0.14
	(6.2)	(6.4)	
Pig	0.6	1.1	0.48
	(4.2)	(11.7)	
Sheep and goats	1.5	1.6	0.91
	(3.4)	(6.7)	
Poultry and rabbit	4.1	6.0	0.23
	(15.3)	(23.2)	
Number of observations	305	295	

Notes: The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. Numbers in parentheses are standard deviations.
Source: Biodigester Rwanda dataset 2012.

Table 14: Households involved in agricultural activities and size of their land

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Households cultivating land (in percent)	97.4	96.6	0.58
Size of cultivated land (in ha.)	2.4	1.9	0.01***
	(2.3)	(1.7)	
Number of locations	4.2	3.4	0.03**
	(4.7)	(4.7)	
Number of cultivated crops	4.4	4.2	0.24
	(1.6)	(1.6)	
Number of observations	288-305	280-295	

Notes: The household questionnaire gathers information on 7 different crops: bananas, beans and peas, cereals, vegetables, fruits, tubers and cash crop. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. Numbers in parentheses are standard deviations.
Source: Biodigester Rwanda dataset 2012.

While the differences in means presented in Table 12 to Table 14 shows that the two groups are quite similar we would also like to establish whether the two groups are similar in terms of the probability of owning a digester. To examine this we estimate the probability of owning a digester as a function of the various socio-demographic characteristics listed in Table 12. Two specifications are estimated (see Table 15). Consistent with the lack of differences in mean characteristics we see that the model has very limited explanatory power (3 to 4 percent) and that apart from two characteristics which are statistically significant in determining ownership, and which we will control for in our impact analysis, the model is not able to discriminate between owners and applicants. In other words, the two groups are similar in terms of the probability of owning a digester.

Overall, the main point emerging from this section is that, on average, the two groups are observationally equivalent. It also confirms that the sampling method outlined in the previous section has led to comparable groups. The lack of difference in terms of observed characteristics supports the idea that in terms of unobserved traits the two groups may not be very different from each other. The implication in terms of identifying an impact is that a simple difference in the means of the outcomes of interest may not be very different from estimates based on multiple regression analysis or propensity score matching.

Table 15: Probit estimates - probability of owning a digester

Dependent Variables	Coefficient (Std. Err.)	Coefficient (Std. Err.)
Household head (HH) is male (=1)	-0.029	-0.046
	(-0.204)	(-0.187)
Age of the HH	-0.002	-0.001
	(-0.005)	(-0.004)
Household size	0.025	0.032
	(-0.022)	(-0.025)
Share of children aged 15 or less in the household	-0.192	-0.298
	(-0.19)	(-0.231)
Share of people aged 65 or more in the household	2.345**	2.041*
	(-1.139)	(-1.11)
HH - years of schooling	0.039**	0.039**
	(-0.018)	(-0.018)
Head of the hh is a farmer (=1)	0.201	0.193
	(-0.208)	(-0.187)
Head of the hh is employed in public act. (=1)	0.06	0.03
	(-0.35)	(-0.323)
Head of the hh is employed in independent occupation (=1)	0.304	0.214
	(-0.262)	(-0.215)
Head of the hh is employed in dependent occupation (=1)	0.099	0.152
	(-0.28)	(-0.288)
Household has a bank account (=1)	0.261	0.286
	(-0.278)	(-0.263)
Electricity in the house (=1)	-0.195	-0.237
	(-0.133)	(-0.168)
Household owns 2 cows or more (=1)	-0.008	0.006
	(-0.009)	(-0.011)
Log of per capita expenditure	0.196*	
	(-0.107)	
Second asset quintile (=1)		-0.105
		(-0.151)
Third asset quintile (=1)		-0.088
		(-0.142)
Fourth asset quintile (=1)		0.098
		(-0.232)
Fifth asset quintile (=1)		0.169
		(-0.245)
South district (=1)	0.04	-0.001
	(-0.077)	(-0.089)
North district (=1)	0	0.115
	(-0.099)	(-0.072)
East district (=1)	0.049	0.076
	(-0.065)	(-0.064)
West district (=1)	-0.098	-0.027
	(-0.101)	(-0.086)
Constant	-3.354**	-0.763**
	(-1.5)	(-0.36)
Pseudo R^2	0.039	0.034
Number of observations	556	597

Notes: *p<0.10, ** p<0.05, *** p<0.01. The 'head of the household is employed in other activity', 'first asset quintile' and 'Kigali district' are used as reference groups. *Source*: Biodigester Rwanda dataset 2012.

5.2 Digester purchase, use and reliability

As a prelude to the discussion of impact, this section provides a range of details on source of knowledge about digesters, decision-making regarding the purchase of a digester, financing digesters, as well as on the use and reliability of the digesters.

A majority of the households stated that they first heard of digesters and their potential benefits from NDBP representatives or NDBP field workers (slightly more than 50 percent) followed by local authorities (20 percent), friends and relatives (11 percent) and from neighbours (10 percent). Armed with this information households face two decisions, first, whether to purchase or not and second what size to purchase.

As shown in Table 16: Decision maker on digester purchase and size, in percent there are sharp differences in terms of the main individual/entity taking these two decisions. With regard to the first choice, in 45 percent of the cases the decision is made collectively followed by the (typically male) household head (39 percent). Only rarely does the (typically female) spouse of the household head take this decision by herself (1.3 percent). Turning to the second decision we see that the onus of decision making is shared equally between the household head (32.5 percent of cases) and NDBP (32 percent). This is perhaps not surprising and indeed may be welcome as it is possible that given their experience NDBP employees are able to provide a better match between household needs and digester capacity. The spouse of the household head has a limited role to play in such decisions (main decision maker in 2.3 percent of households).

Clearly women play a limited independent role in deciding digester purchases and sizes. Perhaps their role is more ceremonial as according to BPR officers and responses from households (semi-structured interviews); in order to obtain a loan, an applicant, typically the male head of the household, has to present the bank with a declaration signed by his spouse. This declaration guarantees that the spouse has approved the purchase.

Table 16: Decision maker on digester purchase and size, in percent

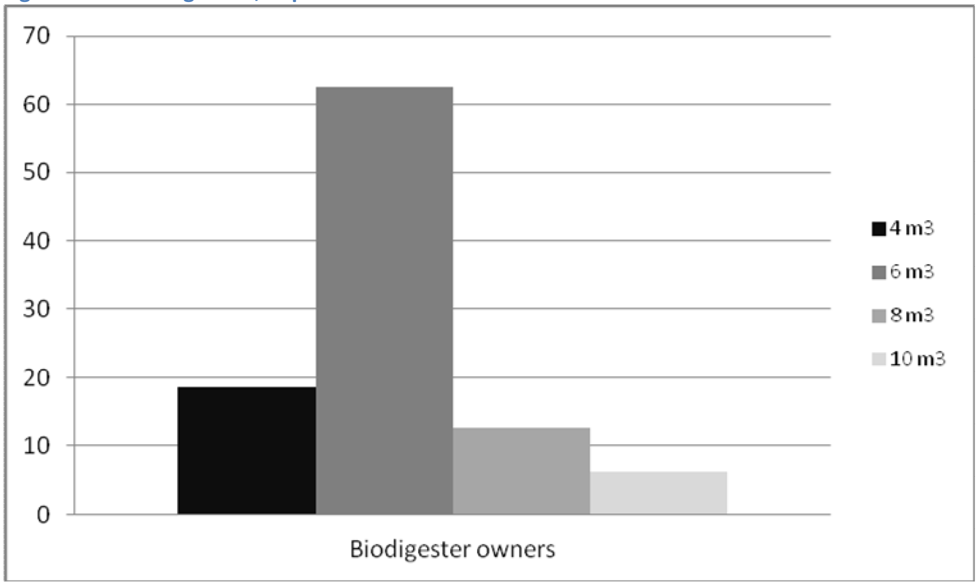
	Digester owners	
	Digester purchase	**Digester size**
Household head	39.0	32.5
Spouse of household head	1.3	2.3
Collective family decision	44.9	28.5
NDBP	4.3	31.8
Other*	10.5	4.9
Number of observations	305	305

Note: 'Other' refers to other relative not living in the household, father / mother of the head of the household and non-relative household members.
Source: Biodigester Rwanda dataset 2012.

Although all 305 households in the treated group should have a completed digester this does not always turn out to be the case. In the case of about 7 percent of households the digester is still being constructed. This is despite the 6 month gap between being listed as having a completed digester and being included in the survey. An important point to be made here is that this deviation introduces a gap between those who are actually treated, that is, those who have a completed and functioning digester and those who are supposed to be treated. Since the aim of the study is to examine the effect of NDBP as opposed to the effect of biogas and we have allowed for a 6 month gap between the time that households appear on a list of households with completed digesters and the survey, we retain these households where the digester is being constructed as part of the treatment group.

Regardless of the state of construction, about 60 percent of the households (189 digesters) in our sample opt for a 6m^3 digester followed by about 18 percent (56 digesters) who prefer a 4m^3 plant (Figure 4). According to NDBP, the new policy is to advise potential applicants to purchase smaller digesters of 4m^3, as these are cheaper and they generate adequate gas (1m^3 a day) to meet cooking needs. Additionally, the daily requirement in terms of cow dung (water) amounts to 30 kilos (30 litres) making it possible for households with only two cows to access the required raw material.

Figure 4: Size of digesters, in percent



Source: Bio digester Rwanda dataset 2012.

Although NDBP informs all the applicants of the possibility of receiving a loan at favourable conditions from Banquet Popularize du Rwanda (BPR), 62 percent of the owners state that they did not use any source of financing but relied only on their own resources (savings) to purchase a digester. An additional 6 percent raised resources by selling an asset and about 12 percent used a combination of their own savings and credit while 14 percent relied exclusively on credit. According to BPR the low loan uptake is due to the fact that a digester investment is not lucrative, that is, the payback time is too long and the potential applicants are sceptical about the technology. Other interviews, e.g., with local government officials, indicated that BPR is too demanding and slow and they would prefer that other financial institutions (especially saving and credit cooperatives – SACCOs) offer loans for such purposes.

In terms of usage patterns, 67 percent of households use biogas for both cooking and lighting while the remainder use it only for cooking. In a majority of households (64 percent) the volume of gas supplied matches expectations, while 25 percent are not satisfied with the volume of production and in the case of about 10 percent of digester owners no gas is being produced.[39]

For the 31 digester owning households (10 percent) whose digesters were not producing gas, 11 did not provide any reasons. In 9 cases construction is still on-going; in the case of 7 the

[39] The lack of satisfaction in terms of the volume of production was also mentioned during the qualitative interviews where respondents mentioned that the amount of biogas produced is not enough for cooking beans –a steady amount of gas for a period of 2 hours is needed to cook beans, an important element of the Rwandese diet.

digester/stove/pipe is damaged in 3 cases there isn't enough cow dung and in one case the household is changing its kitchen. It is likely that these non-functioning digesters will no longer be used as they have, on average, not been producing gas for 120 days. This situation is particularly harmful as households with a non-functioning digester have already paid, or have to repay loans and at the same time have to continue to purchase/collect firewood.

While a majority of owners (64 percent) are satisfied with the amount of biogas produced, about 55 percent of households identified issues other than gas supply as a source of concern. Chief among them was the lack of a second biogas stove and the poor quality of the biogas lamps.[40] Other technical problems mentioned during the qualitative interviews were related to the biogas stoves, mainly corrosion and leaky pipes.

As part of the digester purchase package, NDBP offers a one year warranty including 3 visits from the construction company to check proper functioning of the digester, a training course where owners are trained on plant feeding, repair of broken parts and maintenance. In addition, NDBP provides all owners with a booklet which covers issues related to digester use and management. A majority of owners (80 percent) indicate that they are satisfied with training course. However, the remainder still felt a need for additional training on plant maintenance and repair, advice on the use of bio-slurry and the difference between bio-slurry and other fertilisers.

An issue which arose from the qualitative interviews conducted with NDBP, SNV and user households were concerns about the digester feed stock. There are two issues here, first, initial filling of the digester, a process which might take up to three months and even longer if households have less than 2 cows. Second, in order for the digester to fully function and hence to produce an adequate amount of biogas, a minimal amount of cow dung in combination with water/urine has to be fed daily into the plant. The amount of feed depends on the size of the digester and varies from 30 kilos to 90 kilos of cow dung and the same amount of water. Without proper feeding a plant will not produce an adequate amount of biogas.[41] To give empirical content to these issues and identify the extent of the problem we examined the gap between the amount of recommended feeding and actual feeding.

Table 17 provides digester capacity-specific information on the average amount of dung and water used to feed the digester. On average, it seems that except for the 10m^3 digesters, for the rest, the amount of dung and water used satisfies NDBP requirements (column two and three of the table). For the 10m^3 digesters there is a clear shortfall. While the digester-feeding requirements are 90 litres of water and 90 kilos of dung, the amount used is 72 kilograms of dung and 67 litres of water.[42]

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[40] Initially, lighing was not a target for NDBP, however, due to high priority given by households to this aspect the program has started promoting the use of mini photo-voltaic lighting systems.

[41] The exact quantitative relationship between underfeeding and gas production does not seem to be clear. However, what is clear from a number of technical reports on the issue is that underfeeding results in a reduction in microbial population and in methane production. For example, see http://www.oregon.gov/energy/RENEW/docs/CREFF/VolbedaFeasiblityStudy.pdf

[42] There is no shortage of water during the rainy season. During the dry season about 67 percent of digester owners do not face any water shortages; 20 percent face shortages at times while about 12 percent indicate that they always face shortages.

Table 17: Cow dung and water used by digester owning households to feed digesters and numbers of cows owned

Size of the biodigester	Average amount of cow dung (kg) used to feed the biodigester	Average amount of water (litres) used to feed the biodigester	Number of cows owned		
			Min.	Max.	Average
4 m3	46.6	45.2	1	30	4.9
6 m3	48.6	48.6	0	50	4.9
8 m3	69.2	68.1	2	46	8
10 m3	71.6	66.6	3	31	11

Note: According to NDBP, a 4 m3 digester needs 30 kilos of cow dung and 30 litres of water daily, a 6 m3 digester needs 50 and 50, a 8 m3 needs 70 and 70, a 10 m3 needs 90 and 90. Each adult cow produces, daily, on average 16-20 kg of dung. *Source*: Biodigester Rwanda dataset 2012.

While these figures suggest that lack of feed is not a major issue, the averages may not be entirely revelatory. Based on a daily average production of 16-20 kilograms of dung, households with a $4m^3$ digester need at least 2 cows, For 6, 8 and 10 m^3 the requirements are minimally 3, 4 and 5 cows.[43] A closer look at the sample data (see Table 18) reveals that 50 (1) of the 189 (56) households with a $6m^3$ ($4m^3$) plant and have less than 3 cows. The same issue occurs for households with larger plants. In the case of $8m^3$ plants, 10 out of 38 households own less than the 4 cows required to feed their digesters and in the case of $10m^3$ plants, the corresponding numbers are 4 out of 19 households. Overall, a total of 21.5 percent of the owners do not have the required number of cows to feed their digesters adequately. This does not preclude the possibility that digester owners may be able to secure cow dung from other farmers in order to meet the feeding requirements of their digesters.

Table 18: Distribution of number of digester owners conditional on digester size and cows owned

Size of digester	Number of digester owners possessing				
	0 cows	*1 cow*	*2 or more cows*		
4 cubic meter	0	1	55		
	0 cows	*1 cow*	*2 cows*	*3 or more cows*	
6 cubic meter	10	6	34	139	
	0 cows	*1 cow*	*2 cows*	*3 cows*	*4 or more cows*
8 cubic meter	0	0	3	7	28

Size of digester						
	0 cows	*1 cow*	*2 cows*	*3 cows*	*4 cows*	*5 or more cows*
10 cubic meter	0	0	0	1	3	15

Source: Biodigester Rwanda dataset 2012. For three digester owners, the size is not available. The figures indicate the number of digester owners conditional on size and cows owned. For instance, of 189 digester owners who have a 6 cubic meter digester, 10 possess 0 cows; 6 possess 1 cow, 34 possess 2 cows and 139 possess 3 or more cows.

However, to examine link the between digester gas production and having less cows than required, we estimated three regression models (i) the probability of not producing gas (ii) the probability of producing gas as expected and (iii) the probability of producing less gas than expected as a function of a number of other variables and an indicator variable for having less than the required number of cows. The analysis shows a strong link between satisfaction with gas production and having less than the required number of cows. Households with less than the required number of cows are 7 percentage points more likely to report that their plants are not producing gas; 17 percentage points less likely to report that their plants are producing gas as expected; and 11 percentage points more likely to report that their plants are producing gas but less than expected. The analysis clearly displays a strong link between satisfaction with gas production and owning the required number of cows (Table 19).

[43] The amount of cow dung produced by a cow depends on the breed of the cow and on its size. Based on the survey data we estimate that the average amount of daily dung production per cow is 16-20 kilograms.

Table 19: Level of satisfaction with gas production and cow ownership (in percent)

	Digester users with less cows than required ¥
The plant is not producing gas	0.071*
	(0.042)
The plant is producing gas as expected	- 0.174***
	(0.066)
The plant is producing gas but less than expected	0.114*
	(0.061)

Notes: ¥ These are the 21.5 % of households who do not have a sufficient number of cows to feed the digester according to NDBP requirements. Numbers in parentheses are standard errors. * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.

In terms of a first look at the expected effects of access to biogas consider Table 20. The main motivation for purchasing a digester is the expected reduction in firewood collection (76.1 percent) and a reduction in energy related expenditures (84.9 percent) A small proportion of households mention a smokeless kitchen (3.3 percent) and faster cooking (3.4 percent). There is an interesting gap between ex ante benefit patterns and ex post benefits. While expectations with regard to saving resources on firewood and energy-related expenditures appear to be met at least in terms of the incidence of benefits, there is a clear recognition that the use of biogas leads to a cleaner environment (smokeless kitchen, 80 percent of households) and while not as dramatic it seems that the benefits of faster cooking are also underestimated. Digester owners also seem to be more likely to report that they have seen an improvement in their living conditions in the last 3 years (see Figure 5).

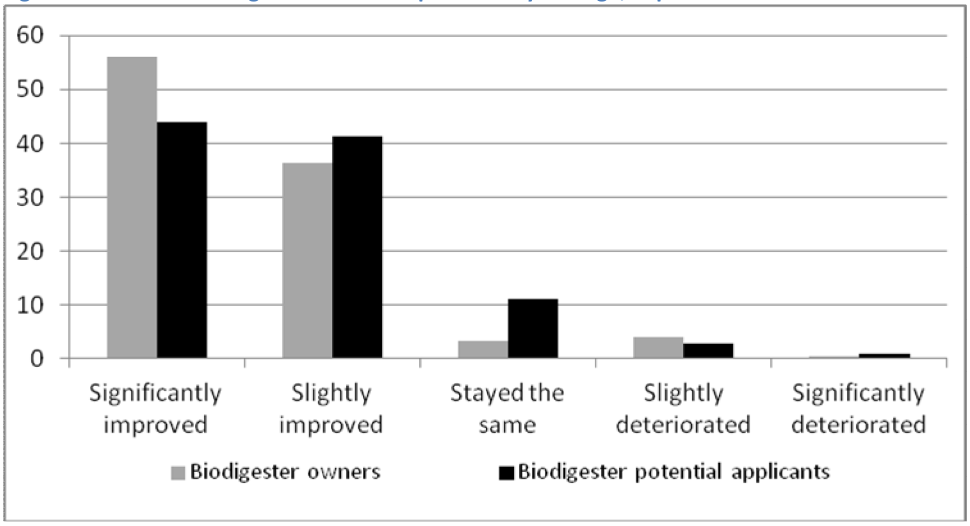
Table 20: Main advantages ex-ante and ex-post of having a digester, in percent

	Ex-ante	Ex-post
Reduction in firewood collection	76.1	89.7
Reduction in energy-related expenditures	84.9	89.1
Smokeless kitchen	3.3	80
Faster cooking	3.6	18.2
Number of observations	305	305

Note: The other reasons for purchasing a digester are mentioned in less than 1 percent of the cases and are: use of bio-slurry as a fertiliser, improve the hygiene of the cow-shed / barn, less effort to have energy, reliable energy supply and subsidy provided. The numbers do not sum up to 100 as each interviewee has been given the possibility to choose multiple answers.

Source: Biodigester Rwanda dataset 2012.

Figure 5: Household living conditions compared to 3 years ago, in percent



Source: Biodigester Rwanda dataset 2012.

5.3 Livestock, bio-slurry and agriculture – comparing owners and applicants

We provide in this section an assessment of the differences in livestock ownership, dung collection and use practices, and the use of bio-slurry and crop yields.[44]

Table 21 provides an overview of the number of each type of livestock owned by owners and potential applicants. While digester owners have, on average, a larger number of cows these differences are not statistically significant. For other livestock as well the differences are not statistically significant.

Table 21: Livestock ownership

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Cow (milking, non-milking and calves)	5.6 (6.2)	4.9 (6.4)	0.14
Pig	0.6 (4.2)	1.1 (11.7)	0.48
Sheep and goats	1.5 (3.4)	1.6 (6.7)	0.91
Poultry and rabbit	4.1 (15.3)	6.0 (23.2)	0.23
Number of observations	305	295	

Notes: The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. Numbers in parentheses are standard deviations.
Source: Biodigester Rwanda dataset 2012.

A very high share of owners and applicants keep their cattle in stables (Table 22). The share of households keeping their cattle within household premises is 100 percent if we include cows kept in courtyards or inside a house. This is an outcome of the zero-grazing policy that has been enacted in

[44] Bio-slurry which is the residue remaining after fermentation of the mixture of dung and water (undigested slurry) in the digester and the release of biogas is an organic fertilizer and may have an effect on crop yields and other agricultural activities. For details on the composition of bio-slurry and its properties see http://www.biru.or.id/en/index.php/bio-slurry/. Accessed on December 10, 2012.

Rwanda. An advantage of this policy, at least from the perspective of the digester is that keeping cows in enclosed spaces reduces the effort needed to collect cow dung to feed the plant. Since both owners and potential applicants own a similar number of cows, the amount of dung collected is about the same for the two groups, but unsurprisingly the use of the dung varies considerably – while digester owners use the cow dung mainly for feeding the digester the main use for potential applicants is as a fertiliser.

Table 22: Cattle and manure management

	Digester owners	**Potential applicants**	***H_0***: $X_{DO} = X_{PA}$ ***p*-values**
Cattle kept in stables (%)	91.2	92.5	0.75
Amount of dung collected daily (kg)	80.6	80.2	0.96
(standard deviation)	(121.80)	(147.68)	
Main use of dung	Used for the digester by 44.8 % of owners	Used as a fertiliser by 81.0 % of applicants	n/a

Notes: Statistics on 'cattle kept in stables' includes 269 (253) digester owners (potential applicants), 'amount of dung collected daily' refer to 305 (295) digester owners (potential applicants), 'main use of dung (relative)' refer to 96 (95) digester owners (potential applicants). The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. *Source*: Biodigester Rwanda dataset 2012.

As shown in Table 23 there are sharp differences in patterns of fertiliser use across the two groups. While both owners and potential applicants rely mainly on cow dung digester owners apply far less per hectare (1,519 versus 4,212 kg per hectare as compared to the control group) and tend to rely more on bio-slurry. The use of chemical fertiliser is rather limited in both groups, although somewhat higher among the control households. In terms of expenditures the greater reliance on cow dung (also bought from other households) and chemical fertilisers, translates into greater monthly expenditure on fertilisers (per hectare) for the control group, although not statistically significant. The time needed to either collect or buy fertiliser is also not statistically different across the two groups, about half an hour per week.

Table 23: Different types of fertiliser used each month, in kilograms per hectare and time spent

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Cow dung	1,519	4,212	0.36
	[287]	[278]	
	(11,617)	(48,267)	
Bio-slurry	558	16	0.00***
	[292]	[277]	
	(1,254)	(161)	
Other dung	29	79	0.27
	[291]	[280]	
	(90)	(760)	
Chemical fertiliser	13	19	0.46
	[286]	[277]	
	(48)	(86)	
Organic matter	65	4	0.30
	[292]	[281]	
	(1,026)	(34)	
Total	2,066	4,081	0.47
	[305]	[295]	
	(11,340)	(46,892)	
Money spent monthly on fertiliser purchase (in RwF)	8,892	20,879	0.41
	[305]	[295]	
	(87,119)	(236,014)	
Time spent per week (minutes) collecting/ buying fertiliser (in minutes)	32	28	0.53
	[305]	[295]	
	(72)	(83)	

Note: Numbers in square brackets refer to the number of digester owners and potential applicants for which the statistics are computed, while numbers in parentheses are standard deviations. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

As mentioned earlier, almost all the interviewed households are involved in agricultural activities, although digester owners tend to own more land in a larger number of locations (Table 24).

Table 24: Households involved in agricultural activities and size of their land

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Households cultivating land (in percent)	97.4	96.6	0.58
Size of cultivated land (in ha.)	2.4	1.9	0.01***
	(2.3)	(1.7)	
Number of locations	4.2	3.4	0.03**
	(4.7)	(4.7)	
Number of cultivated crops	4.4	4.2	0.24
	(1.6)	(1.6)	
Number of observations	288-305	280-295	

Notes: The household questionnaire gathers information on 7 different crops: bananas, beans and peas, cereals, vegetables, fruits, tubers and cash crop. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. Numbers in parentheses are standard deviations.
Source: Biodigester Rwanda dataset 2012.

Despite the relatively small size of the cultivated land, each household cultivates an average of 4 crops. Comparisons of crop output (as reported by farmers) per hectare for different crops (see Table

25) does not display statistically significant differences between owners and potential applicants.[45] Thus despite the differences in fertiliser use patterns between the two groups there is no evidence that this translates into greater crop output. As mentioned earlier, whether bio-slurry is effective depends on the manner in which it is applied, soil conditions and the crop.[46] An on-going project conducted by the Higher Institute of Agriculture and Animal Husbandry (ISAE) and commissioned by MININFRA and NDBP is investigating the effects of bio-slurry use on soil properties, crop growth of potatoes and maize. The study has been implemented in the form of an experiment in which researchers observe output in 6 different allotments which have been fertilized (i) only with bio-slurry (ii) only with chemical fertilisers (iii) with different percentages of chemical fertiliser and bio-slurry. Preliminary results show a positive link between bio-slurry use and plant output but final results are awaited.

Table 25: Annual crop output, in kilograms per hectare

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Bananas	7,270	3,278	
	[195]	[176]	0.30
	(52,792)	(11,388)	
Beans & Peas	1,163	1,588	
	[263]	[259]	0.60
	(7,267)	(11,072)	
Cereals	1,062	1,076	
	[242]	[242]	0.98
	(5,754)	(6,522)	
Vegetables	317	216	
	[204]	[172]	0.49
	(2,035)	(452)	
Fruits	360	405	
	[141]	[98]	0.80
	(1,253)	(1,493)	
Tubers	2,153	2,133	
	[206]	[223]	0.97
	(8,216)	(8,102)	
Cash crops	3,418	2,464	
	[49]	[38]	0.63
	(11,351)	(6,959)	

Notes: Numbers in square brackets refer to the number of digester owners and potential applicants for which the statistics are computed while numbers in parentheses are standard deviations. The last column of the table tests for statistically

[45] The analysis is based on crop output as reported by households and not on the basis of actually measuring crop output.

[46] Studies based on field experiments have demonstrated that the correct application of bio-slurry can enhance agricultural productivity as compared to no fertilizers (Jeptoo *et al.*, 2013) and also compared to the use of chemical fertilizers and manure (e.g. Gurung, 1997; Islam, 2006; Nasir *et al.*, 2012) and this observation is confirmed by studies of farmers' perceptions (e.g. Karki and Expert, 2006; Katuwal and Bohara, 2009). Similarly, some studies based on small scale field experiments with 'model farmers' have found that the application of bio-slurry increases yields for some crops but not for others (Karki, 2001). Laboratory analysis of the chemical properties of bio-slurry suggest that its application can substantially contribute to higher yields, but poor handling practices imply that a considerable share of nutrients is lost at the collection point (Islam, 2006). While there are several studies based on field experiments we could not find any study based on a large sample of farmers and with a treatment-control approach. Methodologically, these studies are small-sample and based on before-after comparisons. Since practice under real conditions can differ substantially from those employed by researchers and model farmers in field experiments and given the limitations of before/after comparisons, it is perhaps not surprising that there is no statistically significant effect of bioslurry on crop yields despite the positive effects reported on the basis of field experiments.

significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012

5.4 Energy expenditures, cooking, lighting – comparing owners and applicants

We commence our analysis of household energy use by first comparing differences in the household budget spent on different items, including energy. For a large number of items the expenditure shares are not particularly different (Table 26). However, there is a discernible difference in the case of energy expenditure with digester owners devoting 4.9 percent less of their budget to energy as compared to potential applicants and spending more on transport and ceremonies and entertainment, although, in all cases the gaps are not statistically different at conventional levels.

Table 26: Household budget shares annual

Typology of expenditure	Entire sample	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Food	27.94	26.85	29.04	0.56
Telecommunication	4.14	3.96	4.33	0.82
Water	3.27	3.75	2.78	0.51
Transport	10.91	12.54	9.28	0.21
Cigarettes / Alcohol / Make up / Hairdresser	6.41	6.54	6.28	0.97
Rent and durables	3.40	3.29	3.51	0.65
Clothes	6.21	6.19	6.23	0.98
Health	3.65	3.91	3.39	0.74
Schooling	13.20	13.40	12.99	0.88
Ceremonies / remittances / entertainment	5.59	6.71	4.46	0.28
Energy	15.23	12.80	17.66	0.08*

Notes: The aggregate 'Energy' consists of expenses for consumable items (fuels) and replacement costs of items such as bulbs but does not include resources spent on appliances such as digesters, lamps, stoves. The shares have been computed for 559 households (280 digester owners and 279 potential applicants). The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.

In absolute terms, while annual expenditure on energy for owners is 126,117 RwF for applicants the figure is 179,332 Rwf. In other words, on an annual basis, owners spend 30 percent less on energy as compared to applicants (see Table 27 and Figure 6). In terms of the source of saving, the reduced expenditure emanates from the lower amounts that owners spend on firewood (26 percent) and charcoal (50 percent) as compared to applicants (Table 27 and Figure 6).[47] While additional analysis is needed to confirm whether this reduction in expenditures may be attributed to biogas, given that the two groups are quite similar in terms of their other attributes (as discussed in section 5.1) it might well be the case.

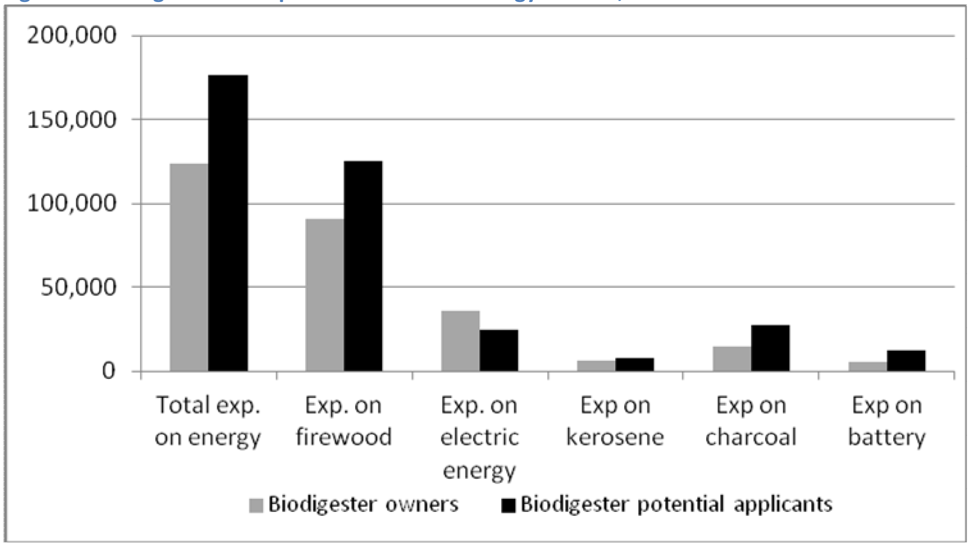
[47] Figure 7 provides information on the incidence of energy use in the last month before the survey.

Table 27: Average annual expenditure on main energy sources (standard deviation in parenthesis), in RwF

Typology of expenditure on energy source	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Expenditure on firewood	95,319	129,087	0.07*
	(291,308)	(175,967)	
Expenditure on electric energy	37,501	24,151	0.03**
	(91,189)	(51,254)	
Expenditure on kerosene	6,156	7,973	0.10*
	(13,371)	(12,674)	
Expenditure on charcoal	13,421	25,789	0.00***
	(36,300)	(69,401)	
Expenditure on batteries (dry cell)	5,738	12,693	0.34
	(8,814)	(121,107)	
Total expenditure on energy	126,117	179,132	0.01***
	(292,972)	(218,130)	

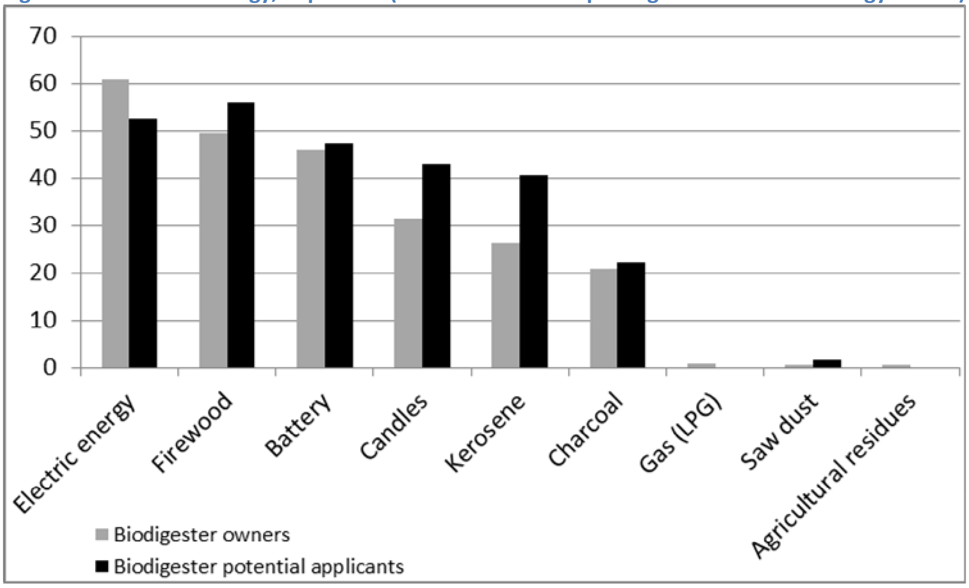
Notes: Expenditures have been computed for the 559 households for whom we have complete expenditure data (280 digester owners and 279 potential applicants). The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). Energy expenditure consists of expenses for consumable items (fuels) and replacement costs of items such as bulbs but does not include resources spent on appliances such as digesters, lamps, stoves. * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

Figure 6: Average annual expenditure on main energy sources, in RwF



Notes: Energy expenditure consists of expenses for consumable items (fuels) and replacement costs of items such as bulbs but does not include resources spent on appliances such as digesters, lamps, stoves. *Source*: Biodigester Rwanda dataset 2012.

Figure 7: Sources of energy, in percent (% of households reporting use of relevant energy source)



Note: The shares do not sum to 100 as all households use more than one source of energy. The figures are the percent of households who have reported the use of a specific energy source in the month before the survey. Electric energy includes energy from six different sources. These are, car battery, individual genset, village genset, solar panel, connected to a neighbour, grid electricity including micro-hydro. *Source*: Biodigester Rwanda dataset 2012.

Cooking behaviour

To dig deeper into patterns of energy use we now turn to examining cooking behaviour and thereafter lighting use. Since they also have a biogas stove, digester owners own more cooking devices. A substantial proportion of households (although not statistically different between treatment and control) have improved stoves and very few households own a gas or a saw dust stove (Table 28).[48] About 6 percent of digester owners do not have a biogas stove. These are mainly digester owners whose digesters are still being built.

Table 28: Households owning different types of cooking devices, in percent

Type of stove owned	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
3-stones	20.0	28.5	0.01***
Improved stove	67.9	72.5	0.11
All metal charcoal stove	13.8	18.0	0.52
Saw dust stove	0.7	0.3	0.61
Gas stove (Liquid Petroleum Gas)	3.9	0.3	0.00***
Biogas Stove	93.8	0.0	0.00***
Average number of stove owned	2.6	2.0	0.03*

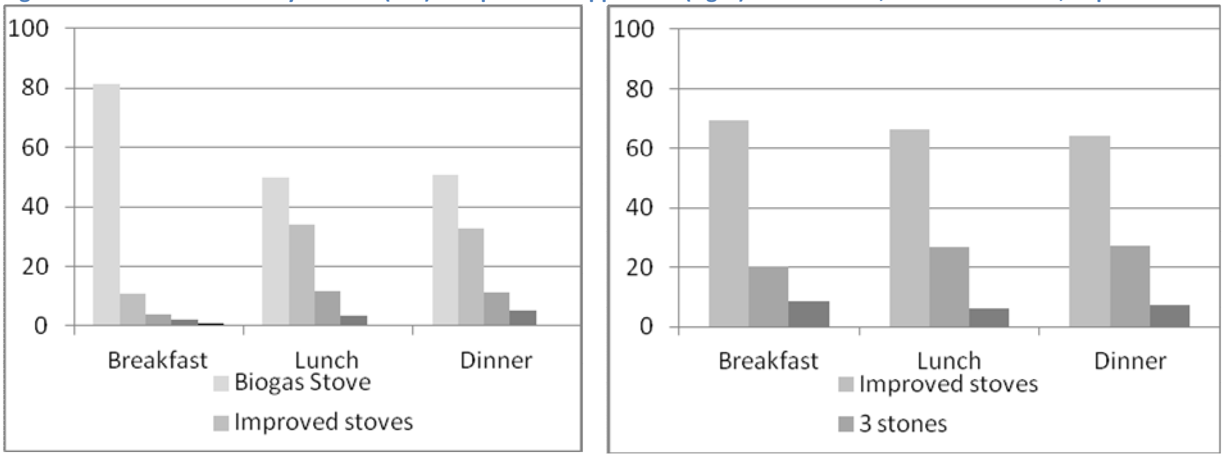
Note: The shares do not sum up to 100 as all households own more than one stove. Statistics are based on 305 digester owners and 295 potential applicants. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

[48] There are several improved cooking stoves *(canamake)* progammes, for both charcoal and wood, operating in Rwanda. These include programmes implemented by MININFRA and by REMA (Rwanda Environmental Management Authority) which is trying to promote the use of the SAVE80 stove. The aim is to spread the use of fuel-efficient stoves in order to reduce the amount of wood and charcoal used for cooking as well as reduce time spent on cooking (see the Annex for pictures).

Most households cook three times a day, for breakfast, lunch and dinner. A comparison of stove use for different meals and for owners and applicants (see Figure 8) reveals interesting patterns. The dominant stove used by digester owners for all meals is the biogas stove followed by improved stoves. For breakfast, the biogas stove is the main stove used by 80 percent of digester owning households, while for lunch and dinner the share drops to 50 percent (improved stoves account for 34 percent, 3-stone stove for 11 percent).

The declining use of the biogas stove over the course of a day may be attributed to the longer time gap available for gas production between dinner and breakfast, the shorter preparation time (less gas needed) for breakfast as compared to lunch and dinner –20, 63 and 65 minutes respectively—and the fact that faster cooking, for which gas is excellent, might be needed in in the morning when several household tasks need to be performed at the same time. While the biogas stove dominates usage it is not a complete substitute as households continue to use other stoves and other fuel sources. As far as potential applicants are concerned the improved stove dominates (main stove used by 65-70 percent of households), followed by 3-stones and all metal charcoal stove. Stove use comparisons shows the sharp displacement effect from improved stoves to biogas stoves as a consequence of having access to biogas. A final point is that despite the high usage rates of biogas stove, as pointed out earlier, 10 percent of digester owners do not have a working plant and during the semi-structured interviews some of these households expressed their concerns and reported that were 'angry at the biogas programme'.

Figure 8: Main stoves used by owners (left) and potential applicants (right) for breakfast, lunch and dinner, in percent



Note: Biogas stoves and saw-dust stoves have been excluded from the figure on the left as they are never used. LPG stoves are never used by the households, neither by the owners or applicants. The shares do not sum up to 100 as all the households own more than one stove. *Source*: Biodigester Rwanda dataset 2012.

As already seen earlier, the main change in terms of energy expenditure emanates from reduced expenditures associated with firewood. This is also evident from Table 29 which shows that the daily demand for firewood and charcoal is lower for owners as compared to applicants. The effect is clearly more pronounced in the case of firewood where the daily consumption is 5 kilograms less as compared to the potential applicants or a yearly reduction of 1,825 kilograms.[49] In addition women in digester owning households spend about half an hour less on cooking as compared to potential applicants – or about 7.6 days less per year.

[49] The quantity of firewood and charcoal used by a household is based on self-reported information. While enumerators were provided with a weighing scale, these were only used in a few cases as households were reluctant to show their stock of wood or did not have any at the time of the visits.

In terms of acquiring firewood, 65 percent of households usually resort to buying wood while the remainder forage. However, in the month prior to the survey 53 percent of the sample households reported that they had purchased fire wood. While, on average, owners spend about 4 hours a week acquiring firewood it is 5 hours per week for applicants although the differences are not statistically significant. However, the actual time spent collecting firewood is hard to estimate as many households often combine firewood collection with other tasks such as collecting grass for cows and working in the field. Firewood collection involves all household members although children are more likely to spend time on this activity.

Table 29: Total amount of fuel consumed per day (standard deviation in parentheses), in kilograms

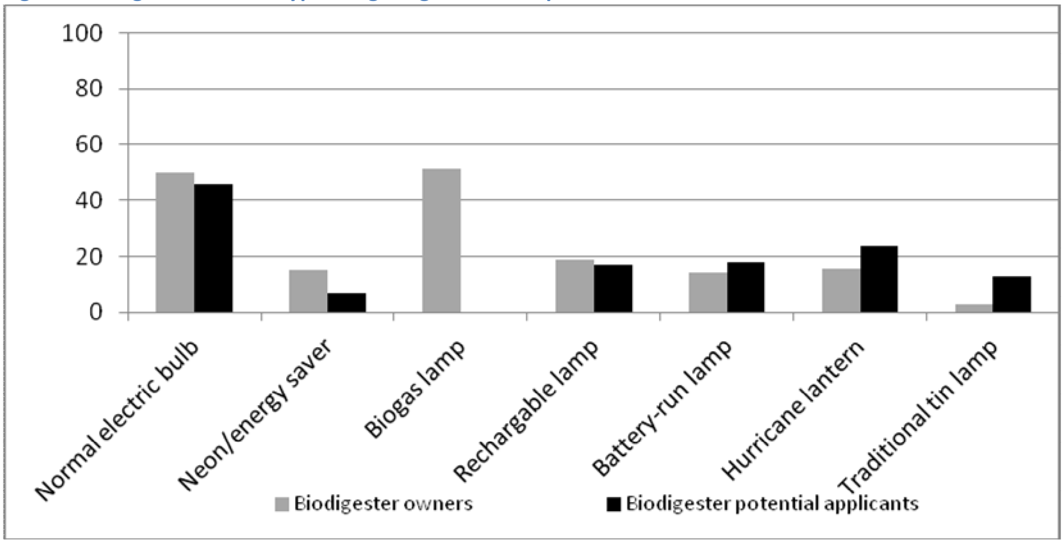
	Digester owners	Potential applicants	***H₀***: $X_{DO} = X_{PA}$ ***p*-values**
Firewood	9.83	14.91	0.00***
	(18.21)	(10.44)	
Charcoal	0.91	1.16	0.44
	(4.71)	(3.38)	
Saw dust	0.07	0.00	0.07*
	(0.70)	(0.00)	
Agric. Residues	0.03	0.02	0.74
	(0.51)	(0.24)	
Time spent cooking(minutes per day)	144	175	0.00***
	(77.50)	(70.43)	
Time spent weekly on gathering/acquiring firewood (hours)	4	5	0.61
	(14.35)	(13.41)	

Statistics are based on 305 digester owners and 295 potential applicants. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

Lighting behaviour

Although biogas is primarily used for cooking, 67 percent of household use it for both purposes. As shown in Figure 9 apart from the presence of a biogas lamp the usage incidence of other sources of lighting is not very different across the two groups. This is not surprising as on average digester owners have less than one biogas lamp (see Table 30). On average the biogas lamp is used for 1.6 hours a day. Owners tend to use lighting for about 5 hours a day as opposed to 3 hours for potential applicants and the entire increase may be attributed to the biogas lamp. Satisfaction levels across different lighting sources (see Figure 10) show that, not surprisingly, households are more satisfied with normal electric bulbs and neon and energy savers (a satisfaction rate of 85 percent) as compared to biogas lamps (70 percent).

Figure 9: Usage of different type of lighting devices, in percent



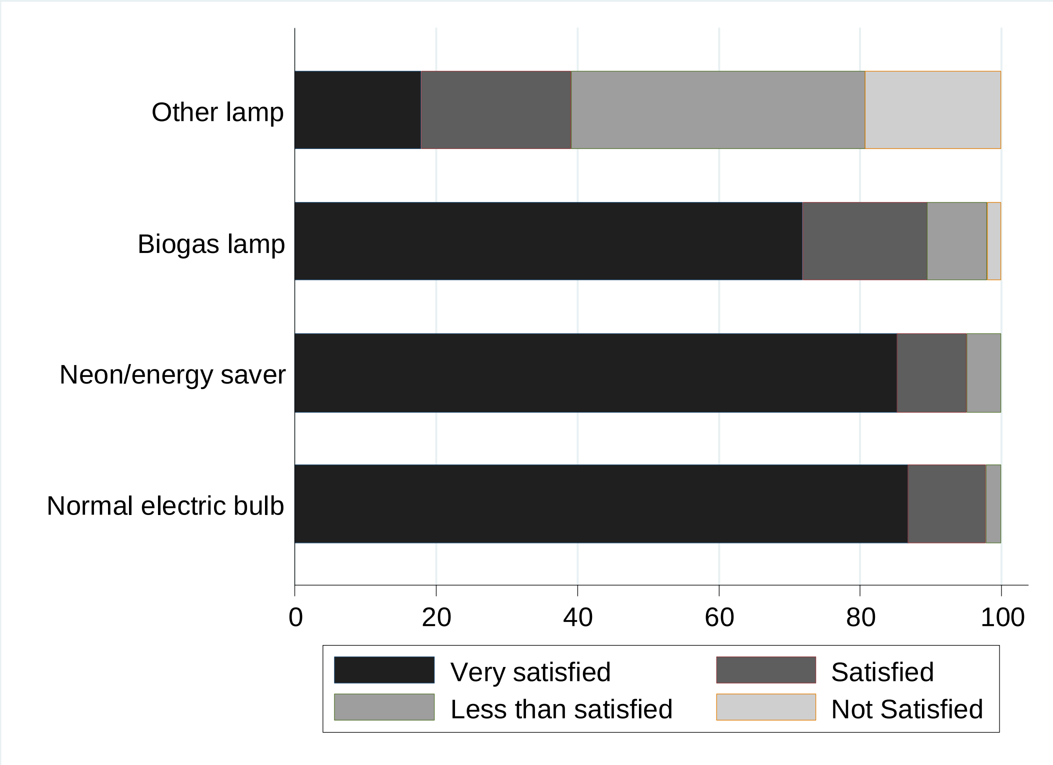
Note: The shares do not sum up to 100 as all households use more than one lighting devices. *Source*: Biodigester Rwanda dataset 2012.

Table 30: Lighting devices used and their daily consumption

	Number of lamps used per household			Lighting hours per day and light device		
	Digester owners	**Potential applicants**	H_0: $X_{DO} = X_{PA}$ ***p*-values**	**Digester owners**	**Potential applicants**	H_0: $X_{DO} = X_{PA}$ ***p*-values**
Normal electric bulb	3.5 (4.8)	3.1 (4.1)	0.31	2.0 (2.4)	1.9 (2.3)	0.71
Neon/energy saver	0.6 (1.9)	0.2 (1.2)	0.01***	0.7 (2.2)	0.5 (2.1)	0.15
Biogas lamp	0.6 (0.6)	0 (0.0)	n/a	1.6 (1.8)	0 (0.0)	n/a
Other	0.3 (0.9)	0.3 (0.8)	0.54	0.6 (1.4)	0.6 (1.7)	0.85
Total	4.9	3.6	0.00***	4.9	3.0	0.09*

Note: Statistics are based on 305 digester owners and 295 potential applicants. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

Figure 10: Level of satisfaction with lighting devices, in percent



Note: The category 'Other lamp' includes rechargeable lamp, battery-run lamp, *hurricane* lantern and traditional tin lamp.
Source: Biodigester Rwanda dataset 2012.

5.5 Smoke, sanitation and health outcomes

Cooking with solid fuels such as firewood and charcoal is expected to have detrimental impacts on health mainly due to the emission of particulate matter and carbon monoxide generated by the combustion process. Various studies have demonstrated the relationship between exposure to particulate matter and respiratory diseases such as lung cancer, pneumonia, or asthma.[50] According to the World Health Organization (WHO 2009), two million people die every year due to household air pollution – more deaths than are caused by malaria (Martin *et al.* 2011). Children are especially vulnerable to smoke emissions and acute respiratory infections rank among the leading causes of child mortality in developing countries (WHO 2002).

The effect of digesters in reducing household air pollution and having an impact on health outcomes depends on the reliance of households on biogas stoves for cooking as opposed to other stoves, ventilation in the kitchen and may also vary across household members. In terms of the cooking context, stove usage patterns have already been described. Additional details are that 90 percent of the households cook indoors, most of them in a separate kitchen building and only 3 percent cook in a room which is part of the dwelling and which may also serve as a living room. In our sample, in virtually all households (97 percent) women are responsible for cooking. In 75 percent of the households a single person is responsible for all cooking although the average for the sample is 1.5

[50] See, for example, Diaz *et al.* (2007), Hosgood *et al.* (2010), Smith-Sivertsen *et al.*, (2009), Smith and Peel (2000), Smith *et al.* (2000), Yu (2011) and Zhang and Smith (2007).

persons per household. In more than half of the interviewed households, the person/people engaged in cooking stay next to the stove for the duration of cooking. Consistent with this pattern, the benefits of having a smokeless kitchen are mostly perceived by female household members and as discussed earlier, 80 percent of households identify a smokeless kitchen as a major unexpected benefit of using biogas (31). In addition, 84 percent of the female respondents in potential applicant households reported that there is always smoke in the kitchen and the corresponding percentage is 56 percent for digester owners.

Table 31: Main advantages ex-ante and ex-post of having a digester, in percent

	Ex-ante	Ex-post
Reduction in firewood collection	76.1	89.7
Reduction in energy-related expenditures	84.9	89.1
Smokeless kitchen	3.3	80
Faster cooking	3.6	18.2
Number of observations	305	305

Note: The other reasons for purchasing a biodigester are mentioned in less than 1 percent of the cases and are: use of bio-slurry as a fertiliser, improve the hygiene of the cow-shed / barn, less effort to have energy, reliable energy supply and subsidy provided. The numbers do not sum up to 100 as each interviewee has been given the possibility to choose multiple answers.
Source: Biodigester Rwanda dataset 2012.

In addition to contributing to a smoke-free environment our analysis suggests that access to biogas is also associated with an increase in improved sanitation practices such as an increase in the frequency of boiling water before drinking, a difference of about 10 percentage points (Table 32 and Table 33).

Table 32: Frequency of households boiling water before drinking (%)

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Always	82.3	71.5	0.00***
	(251)	(211)	
Rarely	11.5	16.3	0.08*
	(35)	(48)	
Never	6.2	12.2	0.01**
	(19)	(36)	

Source: Biodigester Rwanda dataset 2012. Figures in parentheses are number of observations.

Table 33: Times per week a stove is used for sanitation related activities (standard deviation in parenthesis)

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Boiling water for cleaning milk cans	7.3	6.7	0.00***
	(2.4)	(1.7)	
	[236]	[216]	
Heating water for a bath	6.7	6.2	0.01**
	(2.1)	(2.3)	
	[217]	[196]	

Source: Biodigester Rwanda dataset 2012. Figures in parentheses are standard deviations while figures in square brackets are the number of observations.

Whether the less smoky cooking environment and increased frequency of boiling water translate into health benefits needs to be examined. To do so we have gathered information on health indicators which may respond in the short-term such as eye irritations and eye infections (eye conditions), headaches, difficulties in breathing (respiratory diseases). In addition to these, we collected data on the incidence of diarrhoea, intestinal worms and malaria at the level of the individual household member. The first two diseases are related to household hygiene and cleanliness which may be positively influenced due to regular clearing of cow dung. Furthermore, access to biogas may make it easier for households to boil water and reduce the probability of consuming contaminated food or water.[51] Table 34 provides an assessment of the incidence of different diseases across owners and applicants conditional on age and gender. The analysis is based on self-reported illnesses. We comment on whether these figures indicate a difference in health conditions for treatment and control groups in the next section.

Table 34: Incidence of health conditions based on self-reported illnesses, in percent

	Household members aged 19 or more				Household members aged between 6 and 18				Household members aged less than 6	
	Digester owners		Potential applicants		Digester owners		Potential applicants		Digester owners	Potential applicants
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male and female*	*Male and female*
Headaches	9.1	12.2	10.0	11.1	2.4	2.3	2.7	4.7	3.7	1.2
Respiratory disease	4.2	3.6	5.0	3.7	1.2	0.6	1.7	1.4	1.3	0.2
Eye disease	4.7	2.5	3.0	3.4	1.2	1.6	1.5	0.6	2.1	0.8
Malaria	2.3	5.7	2.5	5.7	3.0	2.0	3.3	3.5	4.3	1.0
Diarrhoea	0.6	0.0	0.2	0.2	0.3	0.8	0.7	0.7	1.9	0.7
Intestinal worms and parasites	1.7	0.0	2.4	2.5	0.2	0.5	0.8	0.2	3.4	5.0

Source: Biodigester Rwanda dataset 2012.

5.6 Impact on time use patterns

The use of digesters may affect time allocation of household members through several channels. For instance, access to digesters may reduce the time spent gathering firewood, reduce the time spent on buying/obtaining fertilisers and also reduce time spent on cooking. Time saved on these tasks may be used elsewhere. As we have seen access to biogas increases the number of hours of lighting and this may affect the time-use pattern of children.

Table 35: Time used for gathering firewood (standard deviation in parentheses), fertilisers and cooking

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ ***p*-values**
Time spent daily on collecting/buying fertiliser (minutes)	5 (4.52)	4 (3.95)	0.53
Time spent daily on gathering/acquiring firewood (minutes)	37 (123.01)	42 (114.97)	0.61
Time spent daily on cooking (minutes)	144 (77.50)	175 (70.43)	0.00**
Time spent daily on fetching water (minutes)	70 (174.38)	56 (83.43)	0.35
Time spent daily for mixing the biogas digester (minutes)	32 (31.84)	n/a	n/a
Total (minutes per day)	**288** **(266.75)**	**277** **(121.95)**	**0.49**

Notes: Statistics are based on 305 digester owners and 295 potential applicants. The last column of the table tests for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

[51] A potentially negative effect of digesters is that the absence of smoke in the house or dwelling premises might increase the presence of malaria vectors, although this issue is still under debate (Barghini and de Medeiros, 2010; Tasciotti and Pellegrini, 2012).

Time spent on different activities which are closely linked to digester access is provided in a consolidated form in Table 35. While, on average, time spent on gathering firewood (affects children mainly) and time spent cooking (affects women) is lower for owners, the effects are statistically different only for cooking. Overall, while digester owners spend less time cooking this is balanced by the additional time they need to spend on feeding the digester. However, intra-household use of time is likely to have changed as women do save time on cooking and for men, to the extent that they are responsible for feeding the digester, there is an increase in work burden.

To examine whether these differences in specific tasks translate into any changes in time use across owners and applicants the survey contains a detailed time use module. Based on this module we see (Table 36) minor and in most cases no statistically significant differences in time use patterns for household heads or for any other adult household member. Similarly, for male and female children (Table 37) there are no differences in time-use patterns across the user and applicant groups.

Table 36: Time spent for activities by the head of the household and other members older than 17 years old, in hours

	Head of the household			Household members older than 17		
	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Work	8.52 [270] (2.58)	8.14 [265] (2.51)	0.01***	7.32 [258] (3.29)	7.36 [260] (3.29)	0.85
Household duties	4.39 [173] (4.09)	4.50 [178] (4.11)	0.67	4.39 [238] (4.02)	4.39 [240] (4.02)	0.97
Relax	2.26 [216] (2.08)	2.28 [230] (1.54)	0.40	0.54 [304] (1.14)	0.54 [295] (1.04)	0.12

Note: Numbers in square brackets refer to the number of digester owners and potential applicants for which the statistics are computed while numbers in parentheses are standard deviations. Column 4 and the last column of the table test for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

Table 37: Time spent for activities by the sons / daughters aged 6 – 11, in hours

	Sons between 6 – 11 years old			Daughters between 6 – 11 years old		
	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
Study	1.38 [97] (1.00)	1.32 [96] (0.48)	0.45	1.40 [93] (0.47)	1.41 [75] (1.24)	0.88
Work	1.24 [14] (0.48)	2.08 [9] (0.21)	0.02**	1.24 [11] (0.43)	1.40 [5] (0.37)	0.47
Household duties	3.07 [52] (2.06)	3.07 [48] (2.28)	0.62	3.02 [52] (1.43)	3.34 [38] (2.16)	0.24
Relax	1.34 [36] (0.54)	1.25 [41] (0.28)	0.36	1.36 [33] (0.40)	1.25 [35] (0.30)	0.22

Note: Numbers in square brackets refer to the number of digester owners and potential applicants for which the statistics are computed while numbers in parentheses are standard deviations. Column 4 and the last column of the table test for statistically significant differences in the means for digester owners (DO) and potential applicants (PA). * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Biodigester Rwanda dataset 2012.

5.7 Econometric identification of impacts

As described in section 3, we now provide an econometric analysis of the effects of the NDBP programme. However, before delving into the estimates we reiterate a point made in section 5.2 of this report as well as in the methodological report provided in September 2012. Although all 305 households in the treated group ***should*** have an operational digester this does not always turn out to be the case. In the case of about 10 percent of households construction has not yet started or the digester is still being constructed. This is despite the minimum of 6 month gap between being listed as having a completed digester and being included in the survey. This deviation introduces a gap between those who are actually treated, that is, those who have a completed and functioning digester and those who are supposed to be treated. Since the aim of the intervention is to examine the effect of NDBP as opposed to the effect of owning a functioning digester ***and*** we have allowed for a minimum of 6 month gap between the time that households appear on a list of households with completed digesters and the survey, we retain these households where the digester is being constructed as part of the treatment group. These findings from the household survey data are backed up by interviews carried out during a mission to Rwanda in May 2012 where we were informed that there are cases where even if a digester is completely constructed and households are ***paying for the plant*** it may not be functioning. The upshot is that for those households who are paying for a non-functioning plant the impact of having a digester may be associated with an increase in energy costs.

Indeed, in order not to underestimate the effects of the programme we decided to allow for a time lag between construction and commissioning and restricted our attention to households who according to NDBP have had a digester completed at least 6 months before the survey. At the same time, in order ***not to overestimate*** the effect of the programme, we consider households who are expected to have a completed digester and are paying for it even if it is not functioning as 'treated' and 'beneficiaries' of the program. This represents a balance between concerns about underestimating or overestimating the effect of the programme. Nevertheless, for the sake of completeness we provide a full set of estimates which are based on excluding households with non-functioning digesters (see Annex 1). These estimates should be interpreted as the effect of owning a functioning digester as opposed to the effect of the NDBP programme.

We begin by examining the effects on fertiliser expenditure and crop yield, energy expenditure and use of traditional fuels, time use and smoke and health. We provide estimates based on ordinary least squares (OLS) and propensity score matching. The OLS estimates are based on 303 treatment household and 294 control households while propensity score matching estimates are based on 301 treated and 294 matched controls. Only 2 treated households are not on the common support. This should not be unexpected given the similarities between the treated and control households. In all the tables we provide the marginal effect of being a digester owner on an outcome of interest after controlling for a range of variables which may determine ownership and have an effect on outcomes. Details are provided in the notes to each table.

Fertiliser expenditure and crop yield

Table 38: Impact of digesters on monthly fertiliser expenditure, per hectare (standard errors in parentheses)

Variable	OLS	PSM
Digester owner	-10,411	-9,271
	(14,544)	(18,220)
N	597	595
R^2	0.031	0.034

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Despite the use of bio-slurry and a reduction in the use of chemical fertiliser there is no statistically discernible difference in terms of household expenditure on fertilisers. As shown earlier, the use of chemical fertiliser is quite low in Rwanda and both owners and applicants tend to rely quite heavily on cow-dung, either directly or indirectly through bio-slurry and hence expenditures are not affected. Whether the higher use of bio-slurry translates into greater crop output is analysed in Table 39. Based on crop output, as reported by farmers, we see that for all seven crops there is no evidence that the increased use of bio-slurry translates into an increase in output. As mentioned earlier, research on the best way to use bio-slurry is on-going and as also mentioned by households in our sample, knowledge on how to use bio-slurry in an effective manner is an issue on which they would like more information.

Table 39: Impact of digesters on annual crop yield, kilograms per hectare (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Banana yield, per ha.			*Beans and peas yield, per ha.*		
Digester owner	2,905	2,741	*Digester owner*	-562*	-442
	(2,839)	(2,542)		(318)	(862)
N	597	595	N	597	595
R^2	0.033	.	R^2	0.031	.
Cereals yield, per ha.			*Vegetables yield, per ha.*		
Digester owner	-88	109	*Digester owner*	87	77
	(117)	(530)		(91)	(100)
N	597	595	N	597	595
R^2	0.034	.	R^2	0.017	.
Fruits yield, per ha.			*Tubers yield, per ha.*		
Digester owner	41	56	*Digester owner*	-159	-118
	(80)	(82)		(366)	(658)
N	597	595	N	597	595
R^2	0.025	.	R^2	0.026	.
Cash crops yield, per ha.					
Digester owner	226	280			
	(326)	(333)			
N	597	595			
R^2	0.041	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Energy expenditure and use of traditional fuels

Regardless of relying on simple differences in means, OLS or PSM estimates, the use of a digester is associated with a statistically significant and substantial reduction in annual expenditure on energy. The estimates ranges from 53,215 RwF based on simple differences in means to 57,774 RwF based on PSM or a reduction in costs of between 30 to 32 percent. The main source of savings is a reduction in the expenditure on firewood (39,808 RwF) and cost savings on charcoal is about half that amount. The use of a digester is associated with a 5 kilogram reduction in the daily consumption of firewood which is a 35 percent reduction as compared to applicants. There is evidence for a reduction in the use of charcoal but the effect is not statistically significant.[52]

As outlined above the focus of the analysis is on the average energy savings generated by a digester installed by the programme. However, if we consider energy savings generated by a digester conditional on functioning or in other words the potential effect of the programme if all the digesters installed were functioning then the annual energy cost savings amount to at most 91,633 RwF (see Table A4.54).

Table 40: Impact of digesters on annual energy expenditures (in RwF), and daily consumption (in kilograms) (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Yearly exp. on energy					
Digester owner	-56,426**	-57,774***			
	(27,037)	(22,786)			
N	597	595			
R^2	0.060	.			
Yearly exp. on firewood			*Yearly exp. on charcoal*		
Digester owner	-35,513	-39,808*	*Digester owner*	-15,478***	-19,466***
	(25,554)	(20,576)		(6,799)	(6,077)
N	597	595	N	597	595
R^2	0.058	.	R^2	0.168	.
Daily consumption of			*Daily consumption of charcoal*		
firewood (in kg.)	-5.11***	-4.71***	*(in kg.)*	-.40	-0.36
Digester owner	(1.06)	(1.27)	*Digester owner*	(0.30)	(0.36)
N	597	595	N	597	595
R^2	0.116	.	R^2	0.052	.

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Digesters and time

Possessing a digester and having access to biogas may be expected to reduce the time spent on gathering/foraging for wood and time spent on cooking. As shown below while there is a reduction in time spent on gathering firewood the effects are statistically significant only for time spent on cooking. Women in households which have access to digesters spend about 31 to 37 minutes less per day (an 18 percent reduction) on cooking as compared to applicant households. This is a large effect

[52] Estimates of the amount of firewood saved are consistent with other studies (Arthur et al, 2011; Gautam et al., 2009; Mshandete and Parawira, 2009).

and may be expected to have an effect on time-use in other areas. However, as discussed in the previous sub-section we do not find any changes in time spent on other activities as a consequence of the reduction in time spent cooking. Regardless, it is clear that access to digesters has gender-friendly effects in terms of a reduction in time spent cooking.

Table 41: Digesters and time (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Time spent cooking per day (in minutes) *Digester owner*	-31.63*** (8.91)	-37.25*** (6.77)	*Time spent gathering fertiliser per day (in minutes)* *Digester owner*	0.77 (0.93)	1.39 (1.05)
N	597	595	N	597	595
R^2	0.106	.	R^2	0.05	.
Time spent gathering firewood per day (in minutes) *Digester owner*	-4.65 (6.54)	-6.03 (11.05)	*Time spent fetching water per day (in minutes)* *Digester owner*	20.42 (18.15)	18.72 (16.10)
N	597	597	N	597	595
R^2	0.094	.	R^2	0.047	.

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: Biodigester Rwanda dataset 2012.

Digesters, smoke, sanitation and health

Women's perception of their cooking environment varies sharply across owners and applicants. Respondents were asked about the presence of smoke in their kitchen. While 84 percent of women without digesters mentioned that their kitchens were always smoky the figure was 56 percent for owners. According to the estimates provided below the entire 28 percentage point gap may be attributed to owning a digester.

By reducing the cost of energy, access to biogas may also be expected to lead to better sanitation practices and consistent with the evidence shown in the previous section we find that digester owning households are about 8 percentage points more likely to boil water for drinking purposes. They are also more likely to heat water for bathing and for cleaning milk cans, about 2 times more per month as compared to potential applicants.

Access to a smoke-free environment may be expected to lead to a reduction in the first instance to eye and respiratory related conditions and access to a cheaper source of energy and the possibility of a reduction in food and water contaminants to a more hygienic and relatively disease-free environment. We have examined the potential link between access to a digester and all the self-reported health-related conditions listed in Table 34.

The expectation is that health effects, if any, should be apparent for adult women. There is some evidence of a health effect with a 2 percentage point reduction in self-reported eye diseases for women older than 18 but for the rest of the household members there are no statistically significant effects (see Table 45). Given that the incidence of self-reported eye diseases (see Table 34) is about 3 percent in the sample, the 2 percentage point reduction in the incidence of eye disease is a very large effect. There seems to be no link between digester access and other health conditions such as respiratory diseases, headaches, diarrhoea. There seem to be some effects on the incidence of malaria (but it is inconsistent) and the incidence of intestinal worms (not robust). Overall, the main effects are the presence of a relatively smoke-free kitchen and a reduction in the incidence of eye related conditions.

Table 42: Impact of digesters on the probability of having smoke in the kitchen (standard errors in parentheses)

Variable	Probit	PSM
Smoke in the kitchen		
Digester owner	-0.28***	-0.25***
	(0.03)	(0.03)
N	597	595
Pseudo R^2	0.142	.

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth–ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles and indicators of the district where the household resides. * p<0.10, ** p<0.05, *** p<0.01.

Source: Biodigester Rwanda dataset 2012.

Table 43: Impact of digesters on frequency of boiling water prior to consumption (standard errors in parentheses)

Variable	Probit	PSM
Households boil water before drinking it	0.077**	.062
	(0.034)	(.039)
N	597	598
R^2	0.140	0.034

Source: Biodigester Rwanda dataset 2012.

Table 44: Impact of digesters on frequency of stove usage for sanitation related activities, (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Number of times a stove is used per week for heating water for bath	0.505***	0.461*	*Number of times a stove is used per week for boiling water to clean milk cans*	0.508*	0.581***
	(0.170)	(0.246)		(0.264)	(0.621)
N	411	409		450	447
R^2	0.125	0.033		0.0942	0.029

Table 45: Impact of digesters on the probability of having eye disease in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having eye disease for male members older than 18	0.01	0.03	*Probability of having eye disease for female members older than 18*	-0.02*	-.01
	(0.01)	(0.02)		(0.01)	(0.01)
N	597	595	N	547	595
Pseudo R^2	0.193	.	Pseudo R^2	0.126	.
Probability of having eye disease for male members aged between 6 and 18	0.00	-0.01	*Probability of having eye disease for male members aged between 6 and 18*	0.01	0.03**
	(0.00)	(0.01)		(0.01)	(0.01)
N	498	595	N	421	595
Pseudo R^2	0.234	.	Pseudo R^2	0.120	.
Probability of having eye disease for male and female members aged less than 6	0.00	0.01			
	(0.05)	(0.01)			
N	426	595			
Pseudo R^2	0.186	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.Source: Biodigester Rwanda dataset 2012.

Table 46: Impact of digesters on the probability of having respiratory disease in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having resp. disease for male members older than 18	0.00 (0.01)	0.00 (0.02)	*Probability of having resp. disease for female members older than 18*	-0.00 (0.01)	-0.00 (0.01)
N	597	595	N	597	595
Pseudo R^2	0.079	.	Pseudo R^2	0.132	.
Probability of having resp. disease for male members aged between 6 and 18	0.01 (0.01)	0.00 (0.01)	*Probability of having resp. disease for male members aged between 6 and 18*	Too few data to estimate	Too few data to estimate
N	209	595	N		
Pseudo R^2	0.143	.	Pseudo R^2		
Probability of having resp. disease for male and female members aged less than 6	0.00 (0.00)	0.00 (0.01)			
N	283	595			
Pseudo R^2	0.217	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Table 47: Impacts of digesters on the probability of having headaches in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having headaches for male members older than 18	-0.02 (0.03)	-0.02 (0.03)	*Probability of having headaches for female members older than 18*	0.00 (0.02)	-0.04 (0.15)
N	499	595	N	597	595
Pseudo R^2	0.052	.	Pseudo R^2	0.066	.
Probability of having headaches for male members aged between 6 and 18	0.00 (0.01)	-0.00 (0.02)	*Probability of having headaches for male members aged between 6 and 18*	-0.01 (0.00)	-0.02 (0.02)
N	532	595	N	597	595
Pseudo R^2	0.135	.	Pseudo R^2	0.113	.
Probability of having headaches for male and female members aged less than 6	0.01 (0.00)	0.02 (0.01)			
N	563	595			
Pseudo R^2	0.196	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Table 48: Impact of digesters on the probability of having malaria in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having malaria for male members older than 18	-0.00 (0.00)	-0.02 (0.01)	*Probability of having malaria for female members older than 18*	-0.00 (0.01)	-0.00 (0.02)
N	563	595	N	565	595
Pseudo R^2	0.225	.	Pseudo R^2	0.184	.
Probability of having malaria for male members aged between 6 and 18	-0.00 (0.01)	-0.01 (0.01)	*Probability of having malaria for male members aged between 6 and 18*	-0.01** 0.00	-0.04** 0.02
N	565	595	N	517	595
Pseudo R^2	0.094	.	Pseudo R^2	0.186	.
Probability of having malaria for male and female members aged less than 6	0.01** (0.00)	0.03** (0.00)			
N	563	595			
Pseudo R^2	0.209	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Table 49: Impact of digesters on the probability of having diarrhoea in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having diarrhoea for male members older than 18	0.00 (0.00)	0.00 (0.00)	*Probability of having diarrhoea for female members older than 18*	Too few data to estimate	-0.00 (0.00)
N	207	595	N		595
Pseudo R^2	0.273	.	Pseudo R^2		.
Probability of having diarrhoea for male members aged between 6 and 18	0.00 (0.00)	0.00 (0.00)	*Probability of having diarrhoea for male members aged between 6 and 18*	0.00 (0.00)	-0.00 (0.00)
N	255	595	N	158	595
Pseudo R^2	0.391	.	Pseudo R^2	0.166	.
Probability of having diarrhoea for male and female members aged less than 6	0.00 (0.00)	0.01 (0.01)			
N	403	595			
Pseudo R^2	0.358	.			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

Table 50: Impact of digesters on the probability of having intestinal worms in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having intestinal worms for male members older than 18	-0.00 (0.01)	-0.00 (0.1)	*Probability of having intestinal worms for female members older than 18*	0.00 (0.01)	-0.03*** (0.01)
N Pseudo R^2	341 0.185	595 .	N Pseudo R^2	204 0.177	595 .
Probability of having intestinal worms for male members aged between 6 and 18	0.00 (0.00)	0.00 (0.00)	*Probability of having intestinal worms for male members aged between 6 and 18*	0.00 (0.00)	-0.01 (0.01)
N Pseudo R^2	242 0.424	595 .	N Pseudo R^2	426 (0.235)	595 .
Probability of having intestinal worms for male and female members aged less than 6	-0.01 (0.01)	-0.01 (0.02)			
N Pseudo R^2	597 (0.16)	595 .			

Note: Other regressors include head of the household, his/her age, household size, share of children (old people) below (above) 15 (65) years old, number years of schooling of the head of the household, indicators of the main activity done by the head of the household, controls for household wealth –ownership of bank account, access to electricity, if the household owns 2 or more cows, asset quintiles- and indicators of the districts where the household resides. * p<0.10, ** p<0.05, *** p<0.01.
Source: Biodigester Rwanda dataset 2012.

5.8 Impact at village level

In order to examine the effects of the development of the biogas sector at a more macro level we conducted interviews with the chiefs of 20 villages with more than 5 digester owning households. The primary aim is to gauge whether the development of the biogas sector has led to any discernible effects beyond the level of the household.

Briefly, in terms of a village profile – we find that the villages are similar in terms of a number of observable characteristics. 80 percent ranked dairy farming and agricultural activities as their main economic activities while the remainder ranked the service sector as the main source of income generating activities. The main differences are in terms of population which varies between 250 to 1,700 individuals and income distribution. The latter is based on the perceptions of the chiefs and may not be particularly reliable.

Since digesters represent a relatively new activity and given the low penetration of the program, it should not be surprising that only in 3 cases did the chiefs report that the sector had led to the development of new economic enterprises. These were enterprises concerned with the transportation and sale of bio-slurry. In 8 villages, which turned out to be villages with the highest concentration of digesters (from 10 to 19), a number of additional jobs seem to have been created especially related to digester construction and repair. According to the chiefs these activities mostly employ men. On the flip side in two villages there seem to be signs of diminished business for firewood vendors. The impacts are limited, despite the reduction in the use of firewood and charcoal as reported in the previous sub-section, as the number of digester owners is relatively high but quite low as compared to the total number of households in these villages.

70 percent of the village chiefs indicated that living standards in their villages are better today than they were 3 years ago. In the case of five of these villages the improvement appears to be directly related to the biogas market as they consider that biogas, via bio-slurry responsible for an increase in agricultural productivity. This is surprising as we do not find any evidence of increased agricultural productivity which may be attributed to the use of bio-slurry.

5.9 Benefits and payback period

Based on the analysis presented in the previous section we see that the main financial benefit for digester owners is the 30 to 32 percent reduction in energy costs for digester owners. In absolute terms, at best, this is a reduction of 57,774 RwF per year. There are no statistically significant effects of digester ownership on fertiliser expenditure and nor is there any evidence of an increase in farm output. The bulk of households (62 percent) finance the digester using their own resources and we assume that they could have earned an interest rate of about 6 percent on a long-term savings deposit (in October 2012, BPR offered an interest rate of 4-7 percent on term deposits). Based on the energy savings, the costs incurred by a household to acquire a digester and the opportunity cost of capital we provide a payback analysis for the most commonly installed digester (60 percent of households have a 6 cubic metre digester). The analysis presents payback periods with and without discounting future benefit streams and with and without the subsidy (see Table 51). Analysis conditional on having a functioning digester is provided in Table A4.63. It should be noted that we do not attempt to quantify the monetary value of the effect of cooking in a less smoky environment or the externalities associated with the reduction in the use of firewood.

For the most popular digester the payback period without discounting and without a subsidy is close to 14 years. Adjusting these estimates for the opportunity cost of capital (6 percent) leads to a lengthening of the "without subsidy" payback period to 30 years which is more than the expected 20 year life of a digester. The subsidy shortens the payback period to about 9 years if future flows are not discounted while the discounted payback period is about 13 years.

Table 51: Payback analysis for a 6 cubic metre digester

Without discounting		**Digester owners**
Cost without subsidy (RwF)	800,000	
Cost with subsidy (Rwf)	500,000	
Benefit - annual reduction in energy expenditure (RwF)		57,744
Payback period without subsidy		13.8 years
Payback period with subsidy		8.7 years
With discounting		
Cost without subsidy (RwF)	800,000	
Cost with subsidy (RwF)	500,000	
Benefit - annual reduction in energy expenditure (RwF)		57,744
Payback period without subsidy		30.5 years
Payback period with subsidy		12.6 years

Notes: The analysis is based on a 6 cubic metre digester as 60 percent of households have a digester of this size. Calculations do not include the costs of servicing loans as bulk of households (62 percent) finance the purchase using their own resources and maintenance costs are assumed to be zero. The inclusion of such costs would lengthen the payback period. Energy savings are assumed to remain the same over time. Additional benefits such as reductions in expenditure on fertiliser and increase in crop output are not included as there is no statistically significant evidence that these are being realised at the moment. The discount rate is set at 6 percent, assuming that households are able to earn this rate on a long-term savings account. In October 2012, BPR offered an interest rate of 4-7 percent on term deposits. For instance, the formula used for calculating the discounted payback period without subsidy is Ln(1/(1-(800000*0.06)/57744))/Ln(1.06) or more generally Ln(1/(1-(cost of investment*discount rate)/savings))/Ln(1+discount rate).

6 Summary and concluding remarks

This report has provided an assessment of Rwanda's National Domestic Biogas Programme (NDBP). To meet its objectives the report relied on a household survey which covered digester owning households and households who have shown an inclination to purchase a digester, so called, potential applicants; semi-structured interviews with a range of stakeholders and village-level data collected from a set of villages with a relatively high concentration of digesters. In order to identify the impact of the intervention on various outcomes the analysis relied on cross-section data and a comparison of outcomes between digester owners and potential applicants. The report commenced by providing a background of Rwanda's energy sector and then went on to describe and analyse the functioning of the NDBP. This was followed by examination of the effect of the program on various outcomes, including, patterns of energy expenditure and use of traditional fuels, time-use, smoke and health outcomes, crop yield and fertiliser use.

The NDBP programme has received international and domestic support and is an important element of the country's strategy to reduce dependence on wood as a source of energy. Despite a favourable policy environment and appropriate climatic conditions to support gas production, the programme has fallen short of its targets. By the end of November 2012 the programme had achieved about 15 percent of its originally intended target. The main reason for this shortfall appears to be the large gap between the actual price for a digester versus the price that was used in the feasibility studies. For instance, for the most popular digester ($6m^3$) the ex ante price was pegged at 260,000 RwF but the actual price turned out to be 800,000 or almost three times the anticipated price. This figure amounts to about 2.6 times the annual per adult equivalent consumption in rural Rwanda. Based on the cost savings that are associated with the use of a digester the payback period, without discounting future benefits, for the most popular digester may be expected to be about 9 years with the current subsidy of 300,000 RwF and 14 years without the subsidy.

In addition to the less than expected uptake we found that about 10 percent of the completed digesters were not producing gas at all while 25 percent of digester owners were not satisfied with the volume of production. The two main reasons for no gas production are that digesters are still under construction and digesters/stoves/pipes are damaged. The less than satisfactory gas production is likely to be due to lack of cow dung as our analysis showed that about 21.5 percent of households had fewer cows than are needed to ensure proper functioning of their digesters. These figures, especially the lack of uptake tend to overshadow the success of the programme in other spheres. To reiterate, we found that 80 percent of users have received training, there are 42 active biogas construction companies and that eligible households interested in digesters are able to avail a loan from BPR. These achievements compare quite favourably with the targets laid out by NDBP (see Annex 3).

With regard to the impact of the programme, our sampling strategy appears to have delivered a credible control group. Differences between treatment and control are not pronounced and regardless of the empirical approach we found similar effects. The sharpest effect of the programme was found on reducing energy expenditure and helping households move away from a reliance on firewood and charcoal. Digester owning households spend about 30 percent less on energy as compared to the control group, or at most an annual reduction in expenditure of about 58,000 RwF.

The reduction in expenditure comes mainly from reduced use of firewood (5 kilograms less per day as compared to control households) and charcoal. Other effects include about half an hour less time needed for cooking, a less-smoky cooking environment (a marginal effect of 28 percentage points) and some evidence of positive health effects (a reduction in eye-related conditions for adult women). On the flip side we were not able to detect any effect of the increased use of bio-slurry on crop yields, despite the opinion expressed by some of the village chiefs. Households did mention the need for more knowledge on the appropriate use of bio-slurry which is an area that needs attention. We did not find any statistically significant changes in time spent on obtaining fertiliser and firewood.

Overall, it seems clear that access to biogas offers considerable savings and contributes to a reduction in the use of traditional fuels. However, based on the analysis here we conclude that uptake has been limited mainly due to the high initial costs of obtaining a digester given the socio-economic conditions of rural Rwandan households and the lower than expected benefits as compared to the projections made in the baseline study.

7 Guide to reading: Responses to the evaluation questions

This section provides a guide on where in the text we have dealt with the specific evaluation questions listed in section 2.3 of the terms of reference.

Installation and use (prior to attribution gap)

a. Who (gender specific) in the household has made the decision to install the digester?

This issue is dealt with in Section 5.2 and in Table 16. There are two relevant decisions – the decision to purchase a digester and deciding on the size of the digester. For the former the decision is made collectively in 44.9 percent of cases and by the typically male household head in 39 percent of households. The spouse (typically female) decides in 1.3 percent of households. On the digester size the main decision makers are the household head (32.5 percent) and NDBP (31.8 percent).

b. Did the household apply for a bank loan? For which percentage of the total investment costs?

Please see section 5.2. The bulk of households (62 percent) use their own resources/savings to purchase a digester. 12 percent rely on a combination of savings and credit while 14 percent rely exclusively on credit. The maximum loan offered by BPR is 300,000 RwF for 3 years and 80 percent of those who have borrowed from BPR avail the full amount of the loan. Depending on the size of the digester the loan amounts to between 27 and 86 percent of the subsidized price of a digester.

c. Has the household been properly informed about how to use the digester (e.g. plant initial feeding, presence of user manual)?

See section 5.2. As part of the digester purchase package, NDBP offers a one year warranty and a training course where owners are trained on plant feeding, repair of broken parts and maintenance. In addition, NDBP provides all owners with a booklet which covers issues related to digester use and management. A majority of owners (80 percent) indicate that they are satisfied with the training course. However, the remainder still feel a need for additional training on plant maintenance and repair, advice on the use of bio-slurry and the difference between bio-slurry and other fertilisers.

d. To what extent have installed biogas plants actually been used (gas production)? If not, why?

See section 5.2. In a majority of households (64 percent) the volume of gas supplied matches expectations, while 25 percent are not satisfied with the volume of production and in the case of about 10 percent of digester owners no gas is being produced. There are two main reasons for the zero gas output – lack of cow dung and broken parts which have hampered the functioning of the digesters.

e. What is the digester feed stock?

Please see section 5.2 and in particular Table 17 and Table 18 and the associated discussion. While figures in Table 17 suggest that lack of feed is not a major issue the averages are not entirely revelatory. Based on a daily average production of 16-20 kilograms of dung, households with a $4m^3$

digester need at least 2 cows, For 6, 8 and 10 m^3 the requirements are minimally 3, 4 and 5 cows. A closer look at the sample data (see Table 18) reveals that 50 (1) of the 189 (56) households with a $6m^3$ ($4m^3$) plant and have less than 3 cows. The same issue occurs for households with larger plants. In the case of 8m3 plants, 10 out of 38 households own less than the 4 cows required to feed their digesters and in the case of 10m3 plants, the corresponding numbers are 4 out of 19 households. Overall, a total of 21.5 percent of the owners do not have a sufficient number of cows to feed their digesters adequately.

f. How much is saved in total (per week or month) on 'traditional' energy sources (candles, kerosene, and firewood)? How have expenditures for energy changed?

See section 5.4 and Table 26 and Table 27. Household expenditure on energy amounts to about 13 percent of the annual budget of digester owning households while it is about 18 percent for potential applicants (see Table 26). On average, digester owners experience a 30 percent reduction in annual expenditure on energy or a savings of about 53,000 RwF (126,117 RwF versus 179,132 RwF for treatment and control groups). The reductions come from reduced expenditure on firewood (95,319 versus 129,087) and charcoal (13,421 versus 25,789).

g. Which expenditures does the household reduce in order to finance the investment into the digester?

A very small share of user households (1.4 percent) seems to have cut back on current expenditures. As discussed in (b) above 62 percent of owners have drawn upon their savings to finance the investment.

h. How reliable is the gas supply?

See response above to (d).

Intermediate impact

i. For what purposes is biogas used (cooking, lighting, other)?

See section 5.2. In terms of usage patterns, 67 percent of households use biogas for both cooking and lighting while the remainder use it only for cooking.

j. Has there been any change in time/ workload, disaggregated by gender?

See sections 5.6 and 5.7, Table 35, Table 36 and Table 37. The main effect that we are able to detect is a half an hour reduction in daily cooking time. Since in virtually all households women are responsible for cooking, the time saved accrues mainly to women. There are no discernible changes in terms of time spent on gathering/collecting firewood or fertiliser.

k. To what extent has sanitation improved?

Health effects are in part, an outcome of better sanitation and are discussed in section 5.5 and 5.7. See Table 34 and Table 43 and Table 44. While there is some effect of a reduction in the incidence of eye-related diseases amongst adult females, for most health outcomes we are unable to detect any clear effect.

l. Does the household use the slurry as fertiliser?

See section 5.3 and Table 23. Bio-slurry is used almost exclusively by the user group and it seems that farmers with digesters are replacing the use of cow dung by bio-slurry. However, as indicated in point (c) above farmers expressed a need for additional training on the proper use of bio-slurry. An on-going project conducted by the Higher Institute of Agriculture and Animal Husbandry (ISAE) and commissioned by MININFRA and NDBP is investigating the effects of bio-slurry use on soil properties, crop growth of potatoes and maize. The study has been implemented in the form of an experiment in which researchers observe output in 6 different allotments which have been fertilized (i) only with bio-slurry (ii) only with chemical fertilisers (iii) with different percentages of chemical fertiliser and bio-slurry. Preliminary results show a positive link between bio-slurry use and plant output but final results are awaited.

Impact

m. To what extent do activities during evening hours change due to improved lighting usage? Have study hours/ reading time of children changed?

See section 5.4 and Table 30 as well as section 5.6. While there is an increase in the hours of lighting for digester owners (4.9 hours versus 3) with the entire increase coming from the use of a biogas lamp, there is no evidence that this translates into changes in study hours or reading time (see Table 36 an Table 37). This may be linked to the quality of the light produced by a bio-gas lamp.

n. For what purposes is the time saved been used, disaggregated by gender?

While we do find a reduction in time spent on cooking by women (see (j) above) there is no statistically significant evidence that it influences overall patterns of time use.

o. To what extent has indoor air pollution been reduced (perception of users only)?

See section 5.5 and section 5.7 (Table 42). While 84 percent of women without digesters mentioned that their kitchens were always smoky the figure was 56 percent for owners. According to the estimates provided in Table 42 the entire 28 percentage point gap may be attributed to owning a digester.

p. To what extent have health conditions (in particular respiratory illnesses) changed, specifically among women and children?

We have examined the potential link between access to a digester and a variety of health-related conditions. The expectation is that health effects, if any, should be discernible for adult women. There is some evidence of a health effect with a 2 percentage point reduction in eye diseases for women older than 18 but for the rest of the household members there are no discernible effects (see Table 45). Given that the incidence of eye diseases (see Table 34) is about 3 percent in the sample, the 2 percentage point reduction in the incidence of eye disease is a very large effect – a 66 percent reduction in eye diseases for owners as compared to applicants. There seems to be no link between digester access and other health conditions such as respiratory diseases, headaches, diarrhoea. There seem to be some effects on the incidence of malaria (but it is inconsistent) and the incidence of intestinal worms (not robust). Overall, the main effects are the presence of a relatively smoke-free kitchen and a reduction in the incidence of eye related conditions (see Table 42 to

Table 50).

q. To what extent has comfort/convenience changed, disaggregated by gender? What monetary value do households attribute to this increased convenience?

The main effects seems to be a reduction in energy expenditure (annual savings of about 53,000 RwF based on simple differences and about 57,000 RwF based on the econometric analysis), a reduction in time spent cooking for women (about half an hour) and increased probability (28 percentage point higher as compared to applicants) of working in a relatively smoke-free environment. Based on their own assessment households mention that on average they save RwF 14,000 per month on energy which is much higher than the amount based on their responses to their expenditure decisions. However, only a small percentage of households responded to the self-assessed question.

r. Has the availability of biogas triggered new economic activities? Which ones?

This issue was examined based on village-level information. A discussion appears in Section 5.8. Since digesters represent a relatively new activity and the penetration rate is low, only in 3 cases did village chiefs report that the sector had led to the development of new economic enterprises. These were enterprises concerned with the transportation and sale of bio-slurry. In 8 villages, which turned out to be villages with the highest concentration of digesters (from 10 to 19), a number of additional jobs seem to have been created especially related to digester construction and repair. According to the chiefs these activities mostly employ men. On the flip side in two villages there seem to be signs of diminished business for firewood vendors. The impacts are limited, despite the reduction in the use of firewood and charcoal as reported in the previous sub-section, as the number of digester owners is relatively high but quite low as compared to the total number of households in these villages.

s. What (if any) are the un-intended impacts?

The main unintended impact that we have to been able to detect is displayed in Table 20. While, ex ante, only 3.3 percent of households thought that a smokeless kitchen is an advantage associated with the use of biogas, ex post the figure is 80 percent.

t. How many households (as share of the sample population) keep on using traditional stoves?

A discussion of stove use and cooking behaviour is provided in section 5.4. Please see Table 28 and Figure 8. A substantial proportion of households (although not statistically different between treatment and control) have improved stoves (about 70 percent) and very few households own a gas or a saw dust stove. About 24 percent of households continue using a traditional 3-stone stove. The dominant stove used by digester owners for all meals is the biogas stove followed by improved stoves. For breakfast, the biogas stove is the main stove used by 80 percent of digester owning households, while for lunch and dinner the share drops to 50 percent (improved stoves account for

34 percent, 3-stone stove for 11 percent). The declining use of the biogas stove over the course of a day may be attributed to digester feeding patterns (mainly in the evening) and the time gap available for gas production between dinner and breakfast. While the biogas stove dominates usage it is not a complete substitute as households continue to use other stoves and other fuel sources. As far as potential applicants are concerned the improved stove dominates (main stove used by 65-70 percent of households), followed by 3-stones and all metal charcoal stove. Stove use comparisons shows the sharp displacement effect from improved stoves to biogas stoves as a consequence of having access to biogas.

u. How have cooking and lighting habits changed due to the use of biogas?

For a discussion of these issues see section 5.4. For changes in cooking habits see point (t) above. On lighting (see Table 30) the main change is that digester owners use more lighting per day (4.9 hours versus 3 hours) and the entire increase may be attributed to the use of the biogas lamp.

v. Based on secondary sources, what is the effect of digester slurry on agriculture (use and sale of fertiliser, expenditure on fertiliser, frequency of manure collection, crop yields)?

Analysis of these issues is provided in section 5.3, Table 23, Table 24 and Table 25 and in section 5.7, Table 39. We are unable to detect any effect of bio-slurry or crop yields. While digester owning households tend to use extensive amounts of bio-slurry (Table 23) there are no statistically significant differences in expenditure on fertiliser. Manure is collected daily and on average households collect about 80 kilograms of dung.

w. What have been the changes in farming, in particular livestock management (free roaming versus zero-grazing, number of livestock, etc.)?

A very high share of owners and potential beneficiaries (about 92 percent) keep their cattle in stables (section 5.3, Table 22). The share of households keeping cattle within household premises amounts to 100 percent if we include cows kept in courtyards or inside a house. The introduction of the biodigester is unlikely to have changed these patterns as Rwanda enacted a zero-grazing policy in 2009.

x. Have additional jobs been created in the biogas business sector (contractors, masons, input supply), disaggregated by gender?

Please see section 5.8 and response to point (r) above.

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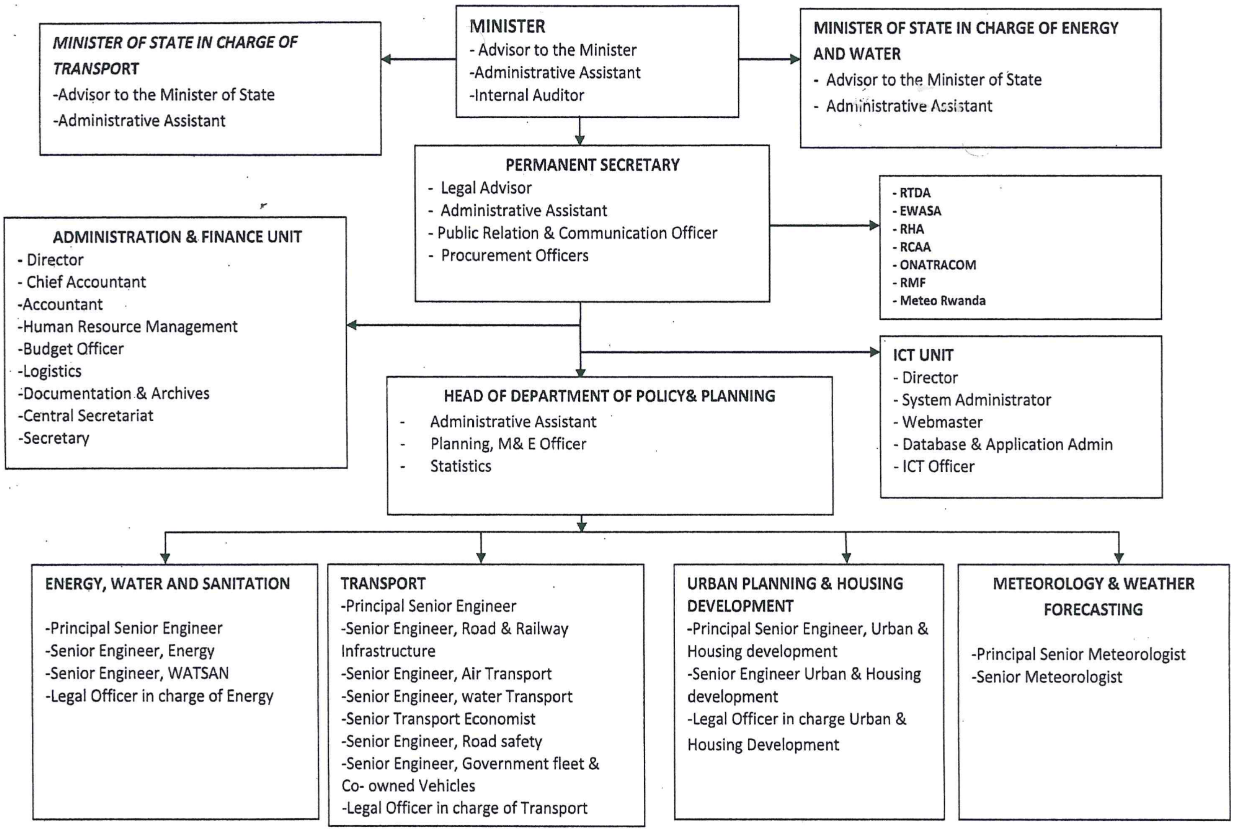
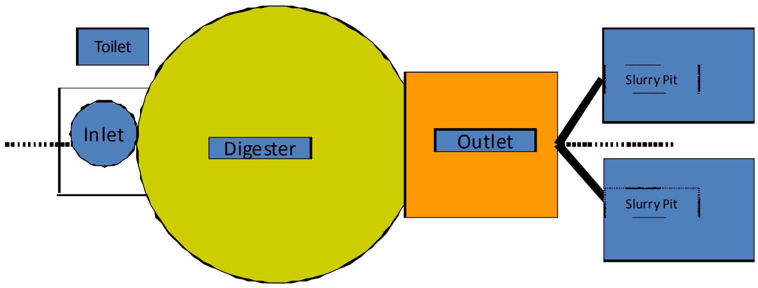
9. Annex 1: Organizational chart of the Ministry of Infrastructure



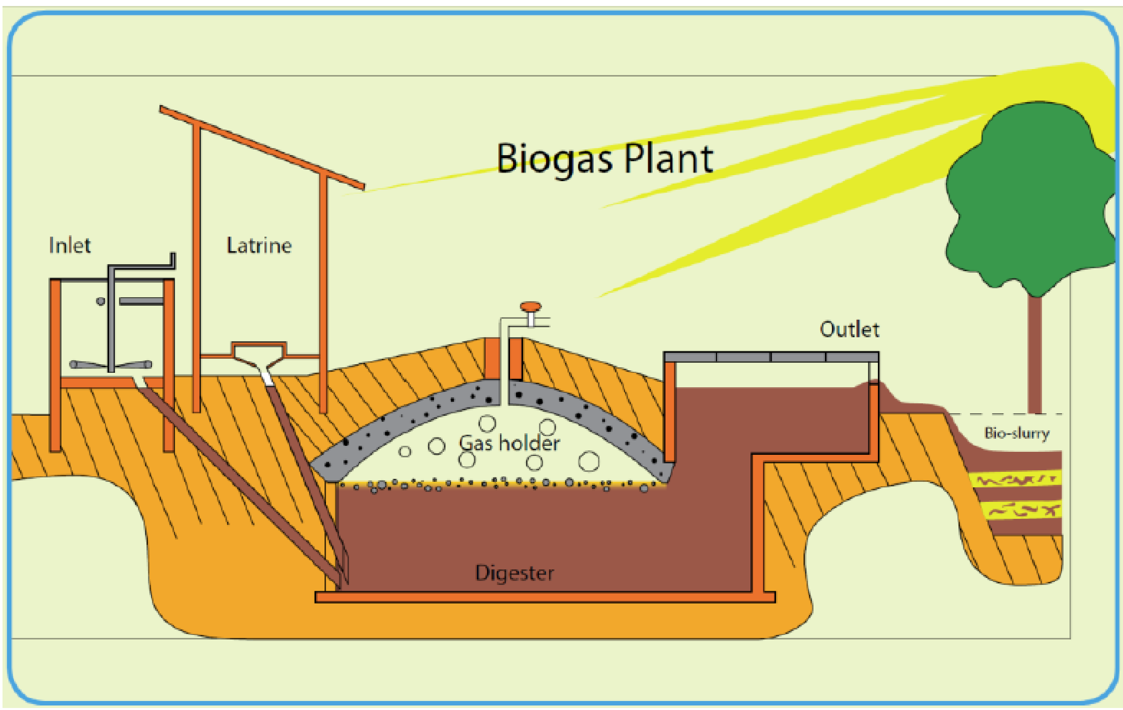
Source: http://www.mininfra.gov.rw/fileadmin/New_structure/MININFRA_STRUCTURE.pdf accessed the 29/01/2013)

10.Annex 2: Digester layout, construction and operation (pictures)

Layout of a digester – top/plan view



Layout of a digester – elevation/side view



Source: All drawings and photographs were provided by NDBP or by the evaluation team, except for layout of a digester – elevation/side view which is from van Nes (2007).

To operate a biodigester, dung and liquid (water and/or urine) are mixed and fed through an inlet. The mix enters the digester where anaerobic (oxygen-free) processes decompose the organic matter and generate biogas/methane. The generation of gas increases the pressure in the digester and allows for the outflow of gas and the by-product. The gas is conveyed to residential dwellings where it can be used for cooking purposes (through biogas stoves) and for lighting (biogas lamps). The by-product from the process is called bio-slurry and can be used as a fertiliser which may be applied in liquid or solid form, or as compost together with other organic material (e.g. agricultural waste).

A completed digester

Pouring water into the inlet

Mixing the raw materials

A biogas stove

A traditional stove

A biogas lamp

11.Annex 3: Activities and indicators for first phase of the NDBP

Activities	Success Indicator
Biogas plants constructed according to national standards:	
• number	• minimum 75 % achievement
• construction defaults	• maximum 10 %
Operation and maintenance:	
• functioning rate	• minimum 90 %
• utilization of plant capacity	• minimum 80 %
• users training	• minimum 75 % (at least 75 % female)
Institutional development:	
• number of constructors	• at least 12 companies
• number of appliances manufacturers	• at least 2 manufacturers produce efficient appliances
• number of biogas lenders	• at least 2 lenders
• management training	• relevant bank and company staff trained
Maximization of benefits:	
• improved sanitation	• minimum 10 % of beneficiaries have toilet connection
• saving of fuel wood	• 2 555 kg/household/year
• reduction workload	• 912 hrs/household/year
• proper use of slurry	• 70 % of the biogas users

Source: Dekelver et al., 2006

12. Annex 4: Impact of owning a functioning digester

Table A4.52: Impact of owning a functioning digester on annual fertiliser expenditure, per hectare (standard errors in parentheses)

Variable	OLS	PSM
Digester owner	-10,159	-20,828
	(15,008)	(18,248)
N	569	567
R^2	0.03	0.038

Source: Biodigester Rwanda dataset 2012.

Table A4.53: Impact of owning a functioning digester on annual crop yield, kilograms per hectare (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Banana yield, per ha.	234	-439	*Beans and peas yield, per ha.*	-485	-1,304
Digester owner	(437)	(826)	*Digester owner*	(319)	(876)
N	569	567	N	569	567
R^2	0.06	.	R^2	0.03	.
Cereals yield, per ha.	-23	-571	*Vegetables yield, per ha.*	101	86
Digester owner	(126)	(545)	*Digester owner*	(100)	(109)
N	569	567	N	569	567
R^2	0.03	.	R^2	0.02	.
Fruits yield, per ha.	60	-2	*Tubers yield, per ha.*	-163	-611
Digester owner	(84)	(85)	*Digester owner*	(365)	(675)
N	569	567	N	569	567
R^2	0.03	.	R^2	0.03	.
Cash crops yield, per ha.	167	158			
Digester owner	(319)	(346)			
N	569	567			
R^2	0.04	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.54: Impact of owning a functioning digesters on annual energy expenditures (in RwF), and daily consumption (in kilograms) (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Yearly exp. on energy	-82,581***	-91,633***			
Digester owner	(17,034)	(18,351)			
N	569	567			
R^2	0.14	.			
Yearly exp. on firewood	-59,258***	-66,861***	*Yearly exp. on charcoal*	-17,081***	-13,893***
Digester owner	(14,295)	(15,626)	*Digester owner*	(6,823)	(5,478)
N	569	567	N	569	567
R^2	0.15	.	R^2	0.17	.
Daily consumption of firewood (in kg.)	-5.45***	-5.54***	*Daily consumption of charcoal (in kg.)*	-0.76***	-.89***
Digester owner	(1.06)	(1.37)	*Digester owner*	(0.23)	(0.28)
N	569	567	N	569	567
R^2	0.12	.	R^2	0.06	.

Table A4.55: Functioning digesters and time (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Time spent cooking per day (in minutes)	-35.39***	-38.55***	*Time spent gathering fertiliser per week (in minutes)*	5.46	9.57
Digester owner	(9.88)	(7.01)	*Digester owner*	(6.67)	(7.46)
N	569	567	N	567	567
R^2	0.11	.	R^2	0.06	.
Time spent gathering firewood per week (in minutes)	-0.03	0.04			
Digester owner	(0.81)	(1.33)			
N	569	567			
R^2	0.10	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.56: Impact of functioning digesters on the probability of having smoke in the kitchen, (standard errors in parentheses)

Variable	Probit	PSM
Smoke in the kitchen	-0.32***	-0.29***
Digester owner	(0.04)	(0.04)
N	569	567
Pseudo R^2	0.16	.

Table A4.57: Impact of functioning digesters on the probability of having eye disease in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having eye disease for male members older than 18	0.01 (0.01)	0.03 (0.02)	*Probability of having eye disease for female members older than 18*	-0.01* (0.01)	-0.01 (0.01)
N	569	567	N	524	567
Pseudo R^2	0.18	.	Pseudo R^2	0.12	.
Probability of having eye disease for male members aged between 6 and 18.	0.00 (0.00)	-0.00 (0.01)	*Probability of having eye disease for male members aged between 6 and 18*	0.02 (0.01)	0.02 (0.01)
N	475	567	N	404	567
Pseudo R^2	0.24	.	Pseudo R^2	0.13	.
Probability of having eye disease for male and female members aged less than 6	0.00 (0.00)	0.01 (0.01)			
N	322	567			
Pseudo R^2	0.16	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.58: Impact of functioning digesters on the probability of having respiratory disease in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having resp. disease for male members older than 18	0.00 (0.02)	0.00 (0.02)	*Probability of having resp. disease for female members older than 18*	-0.00 (0.01)	-0.00 (0.02)
N Pseudo R^2	569 0.07	567 .	N Pseudo R^2	569 0.13	567 .
Probability of having resp. disease for male members aged between 6 and 18	0.00 (0.01)	0.00 (0.01)	*Probability of having resp. disease for male members aged between 6 and 18*	Too few data to estimate	-0.01 (0.01)
N Pseudo R^2	200 0.20	567 .	N Pseudo R^2		567
Probability of having resp. disease for male and female members aged less than 6	0.00 (0.00)	0.00 (0.01)			
N Pseudo R^2	268 0.22	567 .			

Source: Biodigester Rwanda dataset 2012.

Table A4.59: Impacts of functioning digesters on the probability of having headaches in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having headaches for male members older than 18.	-0.03 (0.03)	-0.01 (0.03)	*Probability of having headaches for female members older than 18*	0.01 (0.02)	0.01 (0.03)
N Pseudo R^2	477 0.06	567 .	N Pseudo R^2	569 0.07	567 .
Probability of having headaches for male members aged between 6 and 18	0.04 (0.01)	0.00 (0.02)	*Probability of having headaches for male members aged between 6 and 18.*	-0.01 (0.00)	-0.03 (0.02)
N Pseudo R^2	505 0.13	567 .	N Pseudo R^2	569 0.10	567 .
Probability of having headaches for male and female members aged less than 6	0.01 (0.01)	0.03** (0.01)			
N Pseudo R^2	535 0.20	567 .			

Source: Biodigester Rwanda dataset 2012.

Table A4.60: Impact of functioning digesters on the probability of having malaria in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having malaria for male members older than 18	-0.00 (0.00)	-0.03 (0.01)	*Probability of having malaria for female members older than 18*	-0.00 (0.01)	-0.02 (0.02)
N	535	567	N	538	567
Pseudo R^2	0.22	.	Pseudo R^2	0.19	.
Probability of having malaria for male members aged between 6 and 18	0.00 (0.01)	-0.00 (0.02)	*Probability of having malaria for male members aged between 6 and 18*	-0.01 (0.00)	-0.04* (0.02)
N	538	567	N	495	567
Pseudo R^2	0.09	.	Pseudo R^2	0.18	.
Probability of having malaria for male and female members aged less than 6	0.00* (0.00)	0.02 (0.01)			
N	535	567			
Pseudo R^2	0.21	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.61: Impact of functioning digesters on the probability of having diarrhea in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having diarrhea for male members older than 18	0.00 (0.00)	0.00 (0.00)	*Probability of having diarrhea for female members older than 18*	Too few data to estimate	-0.00 (0.00)
N	170	567	N		567
Pseudo R^2	0.21	.	Pseudo R^2		.
Probability of having diarrhea for male members aged between 6 and 18	0.00 (0.00)	-0.00 (0.00)	*Probability of having diarrhea for male members aged between 6 and 18*	-0.00 (0.00)	0.00 (0.00)
N	170	567	N	152	567
Pseudo R^2	0.43	.	Pseudo R^2	0.17	.
Probability of having diarrhea for male and female members aged less than 6	0.00 (0.00)	0.01 (0.01)			
N	354	567			
Pseudo R^2	0.33	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.62: Impact of functioning digesters on the probability of having intestinal worms in the last six months, (standard errors in parentheses)

Variable	Probit	PSM	Variable	Probit	PSM
Probability of having intestinal worms for male members older than 18	-0.00 (0.01)	-0.00 (0.01)	*Probability of having intestinal worms for female members older than 18*	0.00 (0.01)	-0.02*** (0.01)
N	329	567	N	204	567
Pseudo R^2	0.18	.	Pseudo R^2	0.18	.
Probability of having intestinal worms for male members aged between 6 and 18	0.00 (0.00)	-0.00 (0.00)	*Probability of having intestinal worms for male members aged between 6 and 18*	-0.00 (0.00)	-0.00 (0.01)
N	232	567	N	402	567
Pseudo R^2	0.42	.	Pseudo R^2	0.27	.
Probability of having intestinal worms for male and female members aged less than 6	-0.01 (0.01)	-0.02 (0.02)			
N	538	567			
Pseudo R^2	0.17	.			

Source: Biodigester Rwanda dataset 2012.

Table A4.63: Payback analysis for a 6 cubic metre digester

Without discounting		**Digester owners with functioning digesters**
Cost without subsidy (RwF)	800,000	
Cost with subsidy (Rwf)	500,000	
Benefit - annual reduction in energy expenditure (RwF)		91,633
Payback period without subsidy		8.7 years
Payback period with subsidy		5.4 years
With discounting		
Cost without subsidy (RwF)	800,000	
Cost with subsidy (Rwf)	500,000	
Benefit - annual reduction in energy expenditure (RwF)		91,633
Payback period without subsidy		12.7 years
Payback period with subsidy		6.8 years

Notes: The analysis is based on a 6 cubic metre digester as 60 percent of households have a digester of this size. Calculations do not include the costs of servicing loans as bulk of households (62 percent) finance the purchase using their own resources and maintenance costs are assumed to be zero. The inclusion of such costs would lengthen the payback period. Energy savings are assumed to remain the same over time. Additional benefits such as reductions in expenditure on fertiliser and increase in crop output are not included as there is no statistically significant evidence that these are being realised at the moment. The discount rate is set at 6 percent, assuming that households are able to earn this rate on a long-term savings account. In October 2012, BPR offered an interest rate of 4-7 percent on term deposits.
Source: Biodigester Rwanda dataset 2012.

13. Annex 5: Questionnaires

Household questionnaire (provided earlier)

Village questionnaire (provided earlier)

14. Annex 6: Biodigester companies, plants constructed and turnover

Range	Number of companies	Average biogas digester production per year per company (July 2010 to June 2011)	Volume of Yearly business Per Company (July 2010 to June 2011)	Success & Failure Reasons
Very high	2	117,5 plants	\$152,750	• High commitment /ownership • Geographical focus • Good collaboration with banks(Running capital), local authorities & Communities • Strong promotion • Enough hired staff related to specific activities • Regular and good payment of staff
High	5	36 plants	\$46,800	• Commitment • Geographical focus • Reasonable promotion • Owner/director involved in all activities • Regular payment of masons and technician • Good collaboration with local authorities • Low collaboration with financial institutions • Low management skills
Moderate	12	14 plants	\$18,200	• Very Interested in biogas business • Moderate commitment as the owner/ director is involved in other business • Not necessarily located in any specific area of operation • Sometime supported by the program in Promotion • No collaboration with financial institutions • Moderate collaboration with local authorities • Low management skill • Not continuous business which can lead to irregular payment of masons and supervisors • Turnover of masons
Low	14	7 plants	\$9100	• Some are new in the business and it's they 1st experience as a biogas

Range	Number of companies	Average biogas digester production per year per company (July 2010 to June 2011)	Volume of Yearly business Per Company (July 2010 to June 2011)	Success & Failure Reasons
				company • Others with High expectations with biogas business returns while starting • Fully supported by the program in promotion • No collaboration with local authorities • Most not based in a specific area of operation • Low management skills • Irregular payment of staff • High turnover of trained masons and supervisors
Very Low	20	3 plants	$3,900	• Trained without sufficient knowledge of the business • High of expectations on biogas returns • Involved within other business • Not engaged in promotion as they are waiting for lists of farmers • Low entrepreneurship mind-set • Lack of operational funds • Lack of leadership • Lack of confidence

Source: Binamungu et al. (2011)