Caught between necessity and feasibility

Working Paper
No. 589

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The effects of Rwanda's Biogas Programme on energy expenditure and fuel use

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July 2014

ISSN 0921-0210

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Abstract

Dependence on biomass, especially wood, to meet domestic energy needs raises several socio-environmental concerns. In contrast, cattle manure, which may be used to generate biogas, is considered a cleaner and cheaper source of energy. Despite the existence of several initiatives to promote biogas, systematic analyses of the effects of such initiatives are limited. This paper provides such an analysis. We[*] use data from rural Rwanda to examine the effects of access to bio digesters on energy-related expenditures and consumption of traditional fuels. We find that participation in Rwanda's National Domestic Biogas Programme leads to substantial reductions in firewood use and yields large savings. However, a cost-benefit analysis reveals that the attractiveness of participating in the biogas programme is hampered by a long payback period.

Keywords

Energy policy, renewable energy, biogas, Rwanda.

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I. Introduction

The bulk of Rwandese households rely on firewood to meet their domestic energy needs. According to the latest available figures, at the national level, 88 percent of households rely on wood and 8 percent rely on charcoal as their main source of energy (EUEI-PDF GTZ MARGE, 2009). Corresponding figures for rural areas are 95 and 1 percent, respectively (see Table 1). The continued consumption of traditional biomass and lack of alternative energy sources such as liquefied petroleum gas (LPG) or electricity has led to increased pressure on available forest resources (MININFRA, 2008; Ndayambaje and Mohren, 2011) and despite the lack of alternatives, recent legislation has attempted to restrict access to forests (Ndayambaje and Mohren, 2011).

In 2006, motivated by the challenges posed by household dependence on firewood, the Government of Rwanda with technical support from SNV Netherlands Development Organization launched its National Domestic Biogas Programme (NDBP).[1] Rwanda's NDBP, which is amongst the earliest domestic biogas programmes in Sub-Saharan Africa, follows in the wake of programmes established in several Asian countries such as Nepal, India, China and Vietnam. These and other initiatives are expected to deliver a range of benefits to rural households in developing countries. The short-term benefits include a reduction in energy-related expenditures, a reduction in the use of traditional fuels and a reduction in time spent on gathering fuel and cooking. Longer-term benefits include enhanced agricultural productivity due to the use of bio-slurry, a by-product of biogas production which may be used as a fertiliser, improvements in indoor air quality and subsequent health benefits.[2] Notwithstanding these expectations and several years since project implementation, credible evidence on the actual impacts of these programs is limited.

[1] Although, prior to this programme, biogas had not been used to meet domestic needs, *per se,* the use of biogas is not new to Rwanda. Since the late 1990s biogas has been used in various institutions, most notably in prisons but also in schools and hospitals. Rwanda's poo-powered prisons, http://www.bbc.co.uk/news/world-africa-16203507. Last accessed on December 12th, 2012.

[2] Biogas is produced from organic materials such as cow dung through anaerobic digestion. It is mainly composed of methane and is an odourless and colourless gas. While burning it does not produce any soot or particulates.

One of the first examples is provided by Katuwal and Bohara (2009) who examine the effects of access to biogas plants in Nepal on a wide range of outcomes. Their study is based on 461 biogas users located in 15 districts and provides a before-after comparison. The authors reported a 53 percent reduction in the use of firewood and an 81 percent reduction in the time spent collecting firewood. A methodologically similar study, albeit based on a much smaller sample of 12 users conducted in the Peruvian Andes (Garfí *et al.*, 2012) reports a 50-60 percent reduction in firewood consumption. While promising and informative, the lack of a control group in such before-after comparisons raises concerns about the credibility of the analysis.

Alternatively, attempts have been made to identify the effects of access to digesters using a treatment-control approach. One of the earliest such studies comes from India's Planning Commission (Programme Evaluation Organisation, 2002) which examined the effect of India's National Biogas Development Project. The study, based on 615 biogas users and 740 non-users from 133 villages found that the majority of digesters (55 percent) were not operational. Nevertheless, user households experienced a reduction in energy related expenditures (Rs.188 a month) and a 10 kilogram reduction per month in the use of firewood. Based on data from three villages in Western China in 2006 (239 households; 183 users and 56 non-users), Groenendaal and Gehua (2010) concluded that despite working with a sample of relatively long-term digester users the many benefits attributed to the use of digesters have only partly been realized, if at all. They do not find strong fuel substitution effects (biogas replacing coal/firewood) and limited evidence of a reduction in energy related expenditures. For the bulk of the outcomes under scrutiny there were no statistically significant differences between users and non-users. In the case of both these studies, the authors do not provide evidence to support the validity of the control group and their assessments are based on differences in means, without controlling for variables which might influence uptake and outcomes.

Closest to the current context, Laramee and Davis (2013) work with a relatively small sample (40 households; 20 users and 20 non-users) drawn from 7 communities located in Northern

Tanzania. The authors find large effects and conclude that biogas almost completely replaces the use of firewood and kerosene in digester using households and energy-related expenditure in digester using households is only 15 percent of the amount spent by non-user households. While the large positive effects in Tanzania are striking as compared to the less sanguine outcomes in the papers on India and China, the credibility of the estimates is hindered by the small sample size. Furthermore, the control group was identified by asking adopter households to identify a neighbour with similar socio-economic characteristics rather than through an objective approach.

This study adds to the scant literature on the effects of access to digesters. We focus on Rwanda and attempt to provide credible evidence on the effects of the country's NDBP on two key outcomes, namely, whether access to digesters leads to a decline in energy-related expenditure and a reduction in the use of wood. We also provide an exploratory payback analysis designed to assess the viability of the intervention. Methodologically, we rely on cross-section data and employ a treatment-control approach but, as is discussed later in the text, attempt to improve on the existing literature in several ways.

The paper is structured as follows. The next section provides a brief background of the programme. Section 3 outlines the empirical approach while Section 4 discusses the sampling strategy and the data. Section 5 discusses the impact of the programme while section 6 provides a payback analysis. Section 7 contains concluding observations.

2. Rwanda's National Domestic Biogas Programme –A brief summary

In 2006, motivated by the continued reliance on firewood as a domestic energy source and on the basis of feasibility studies which indicated a high biogas production potential, the Government of Rwanda launched a National Domestic Biogas Programme.[3] In 2008, after training and sensitisation,

[3] 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 digester. 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 Dutch Ministry of Foreign Affairs (DGIS) and executed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

the programme became operational. At inception, the programme targeted the installation of 15,000 family sized (between 4 and $10m^3$), high-quality biogas plants by the year 2011. However, a mid-term review conducted in late 2009 led to a rescaling of the target to 5,000 digesters and in 2010 a new target of 3,000 digesters was proposed. By mid-2012, around 1,800 digesters spread over 30 districts had been built. Table 2 contains information on the original targets and the number of digesters actually built.

The programme has an integrated supply and demand approach. On the supply-side, NDBP with the support of SNV provides training on biogas technology and the construction of biogas plants and supports the establishment of digester construction companies. On the demand side, NDBP markets and promotes the use of digesters, provides a subsidy to cover part of the costs (see Table 3) and through Banque Populaire du Rwanda (BPR) has established a facility which provides loans at a favourable rate.[4] The procedure to apply for a 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 eligibility criteria, which includes owning at least two cows and having a bank account, NDBP arranges construction.[5] The digester is covered by a '1 year warranty' and the construction company has to visit the plant to ensure proper functioning. Quality checks are also conducted by program field technicians and as part of the digester purchase package, NDBP offers a course to train users on plant feeding, small repairs and general maintenance.

3. Identifying the impact of digesters

There are a variety of ways in which access to digesters may influence outcomes at the household level. Foremost among these, access to a new energy source may be expected to lead to a substitution away from traditional sources of energy. In the current context case a movement away from wood and charcoal. Since there is less need for households to buy or gather traditional fuels, both energy expenditures and time spent acquiring fuel may be expected to decline. Other potential

[4] The loan is limited to a maximum of 300,000 RwF for 3 years at 13% percent interest, versus around 17% in the market.

[5] The two cow requirement is related to the manure required to generate sufficient biogas.

effects include a less smoky cooking environment and concomitant health benefits as well as improved sanitation practices due to readily available access to energy. In the longer-term, bio slurry a by- product of the production process may be used as a fertilizer and enhance agricultural yields.

This paper focuses on two outcomes - energy expenditure and fuel use, although, we also discuss other outcomes. To identify effect, the evaluation relies 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 main empirical concerns with regard to attribution arise due to two elements. First, the programme is voluntary and requires households to apply for a digester and second, whether an applicant successfully obtains a digester depends on fulfilling eligibility conditions set by NDBP (see preceding section). Due to these two aspects, it is quite likely that those who *apply* and *obtain* a digester are systematically different from those who are not interested (non-applicants) in obtaining a digester.

In order to provide a credible assessment of the effects of owning a digester we developed a control group based on the following protocol. First, we randomly chose a set of controls from a list of "potential applicants" maintained by NDBP.[6] The advantage of working with such a group is that it consists of individuals who have displayed an interest in owing a digester and this should reduce differences in unobserved traits between the treatment and control group. Second, from this universe of control households, we chose households that fulfilled the most important eligibility condition, that is, ownership of at least two cows. Third, as far as possible control households were drawn from the same district and the same village as the treated households.

In principle, it is possible that comparing differences in outcome means between digester owning ($DO_i = 1$) households and a control group ($DO_i = 0$) developed on the basis of the conditions outlined above, will yield credible estimates. However, since there may be other

[6] On the basis of its marketing activities NDBP maintains a list of "potential applicants" with their addresses and phone numbers. These are individuals who have attended information and marketing sessions offered by NDBP and thereafter indicated an interest in owning a digester.

observable differences between digester owning households and the control group we estimate linear regression models such as (1),

$$Y_i = \alpha + \beta DO_i + \gamma X_i + \upsilon_i \,, \qquad (1)$$

where Y_i indicates an outcome of interest and X_i is a vector of variables which may influence both digester ownership and outcomes. The coefficient on DO_i is the object of interest. Provided that after controlling for X_i unobserved characteristics of digester owners and DO_i are not correlated, OLS estimates of (1) should yield unbiased estimates of the effects of owning a digester.

As an additional step, in order to refine our 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). We estimate propensity scores, that is, $\Pr(DO_i = 1 | X_i)$, from a probit regression of owing a digester on observed characteristics (X_i) and use five nearest-neighbour matching to obtain a set of treated and matched controls. The average treatment effect on the treated (ATT) when *N* digester owners are matched to potential applicants (*PA*) may be written as

$$ATT = \frac{1}{N}\sum_{i=1}^{N}(Y_i^{DO} - \sum_{j=1}^{C} W_{ij} Y_j^{PA}), \qquad (2)$$

where Y_i indicates the outcome for each of the different groups and W_{ij} are the weights used to calculate the counterfactual outcome for each digester owner. If the unobserved traits of digester owners and potential applicants are similar, the ATT provides unbiased estimates of the effect of the programme.

4. Sampling strategy, data and descriptive statistics

To implement the empirical strategy we rely on a cross-sectional survey of 600 households, 305 treated and 295 control, conducted in June-July 2012.[7] The sample of treated households was drawn

[7] The overall sample size was set at 600 households, divided into 305 users and 295 applicants households. Power calculations (setting alpha at = 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 and energy related expenditures).

from a set of 1,722 digester owning households who according to NDBP records have a digester whose construction has been completed at least 6 months prior to the survey.[8] The idea is that this lag provides adequate time for households to develop the experience needed to operate a digester and at the same time experience the benefits of owning a digester. The set of control households was drawn from a list of 3,104 households who had indicated interest in owning a digester.

Nationwide coverage is a crucial feature of the program and in order to ensure that the sample reflects this we opted for a stratified random sample. The set of user households was stratified at the district level, and random sampling with probability (of sample inclusion) proportional to the number of user households per district was used to obtain the sample of 305 digester owning households and 295 potential applicants. A list of pre-selected households was provided to enumerators. To ensure comparability, the enumerators checked that the pre-selected applicant households did not yet have a digester and that they owned at least two cows.[9] If these conditions were not met, replacement households living in the same village were identified. Details on the total number of households with a completed digester, the share of treated households, the number of user and applicant households sampled by province and by district are presented in Tables A1 and A2, respectively.

The survey gathered information on a wide range of socio-economic aspects and on household demographics, occupation, education, cooking behaviour, energy-related expenses, fuel use, and time allocation. In addition, the questionnaire contained a detailed section on the reasons for (not) purchasing a digester, on the method used to finance the digester, experience with the digesters and the NDBP.

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[8] 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 6 months and included households in category (iii) as they face financial liabilities even if the digester is not classified as operational.

[9] Telephone numbers were available for 91 percent of the households.

Descriptive statistics for the entire sample as well as for the treatment and control groups are provided in Table 4. Two sets of comments are in order. First, households in the sample under scrutiny are more prosperous as compared to average households in rural Rwanda. To elaborate, comparisons with the nationally representative Demographic and Health Survey (DHS) conducted in 2010 show that the 'biogas' sample is similar to an average household in the DHS in terms of demographic traits - household size, age of household head.[10] However, there are marked differences in socio-economic characteristics. While almost all the sampled households own cattle and have a bank account, the corresponding numbers in the DHS are 30 percent and 29 percent, respectively. A household head in the 'biogas' sample is twice as educated as compared to a household head in the DHS (7.5 versus 3.4). With regard to per capita expenditure, in 2011, at current prices the mean yearly consumption per adult equivalent in rural Rwanda was 207,652 excluding self-consumption or about 27 percent less as compared to households in our sample.[11]

Second, treatment and control households are not remarkably different. There are no statistically significant differences in terms of household demographic composition, occupation of household head, livestock ownership and per capita annual consumption. Even when statistically significant differences exist, the gaps are not pronounced. Digester owners are somewhat more educated (8 vs. 7 years of education) and own more land (2.4 versus 1.9 hectares) than applicants. The limited difference in terms of observed traits suggests that the sampling approach has led to comparable groups and that differences in unobserved traits between the two groups may also not be pronounced.

5. Functioning and impact of digesters

As a prelude to the discussion of impact, this section provides details on the functioning of digesters. Thereafter, we examine differences in means of various outcomes between treatment and control groups and subsequently discuss the econometric estimates.

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[10] See http://www.measuredhs.com/Data/ , last accessed on 25th April, 2013.

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

5.1 Functioning of digesters

About 60 percent of the households (189 digesters) have a 6m^3 digester followed by about 18 percent (56 digesters) who prefer a 4m^3 plant. While a majority of households (65 percent) appear to be satisfied with the volume of gas produced by the digesters, about 25 percent are not and about 10 percent of the completed digesters are not producing any gas. The main reason for lack of production is inadequate digester feed stock. The required amount of feed depends on the digester size and ranges needs between 30 to 90 kilograms of cow dung and the same amount of water. On average, it seems that except for the 10m^3 digesters, the amount of dung and water used satisfies NDBP requirements (columns two and three of Table 5). 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. These 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 digesters the requirements are minimally 3, 4 and 5 cows. A closer look at the sample data (see Table 6) 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 4 cows and in the case of 10m^3 plants, the corresponding numbers are 4 out of 19 households. Overall, 21.5 percent of the owners do not have the required number of cows.[12]

With regard to the non-functioning digesters, 11 of the 30 digester owning households whose digesters were not producing gas could not provide any reasons for it, in 9 cases construction is still on-going, 7 of the digesters are damaged and in 3 cases there isn't enough cow dung. Thus,

[12] 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 showed 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.

despite the 6 month gap between being listed as a household with a completely constructed digester about 10 percent of those with formally completed digesters do not have a digester that produces gas. From the perspective of the evaluation the existence of these non-functioning digesters introduces a gap between those who are supposed to have been treated and those who are actually treated. 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.[13] Since the aim of this study is to examine the effect of the NDBP as opposed to the effect of owning a functioning digester, 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 households with non-functioning digesters as part of the treatment group. However, we also provide estimates where we exclude households with non-functioning digesters. Such estimates should be interpreted as the effect of owning a functioning digester as opposed to the effect of the NDBP programme.

5.2 Impact of digesters

We commence our analysis 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 7). However, there is a discernible and statistically significant 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, the gaps for these items are not statistically different at conventional levels. In absolute terms, while annual energy expenditure for owners amounts to 126,117 RwF for applicants the figure is 179,332 RwF. Thus, on an annual basis, owners spend 30 percent less on energy as compared to applicants (see Table 8). The reduction stems mainly from the lower amounts

[13] 62 percent of the owners state that they did not use any source of financing but relied on their own resources (savings). An additional 6 percent raised resources by selling an asset and about 12 percent used a combination of savings and credit while 14 percent relied exclusively on credit.

spent on firewood (26 percent) and charcoal (50 percent). In absolute terms the savings may be attributed mainly to reduced expenditure on firewood (33,768 RwF). Consistent with these patterns, Table 9 shows that the daily demand for firewood and charcoal is lower for owners as compared to applicants. The effect is more pronounced in the case of firewood where the daily consumption is 5 kilograms less (a 35 percent decrease) or a yearly reduction of 1,825 kilograms.[14]

Econometric estimates based on equations (1) and (2) are provided in Table 10.[15] Regardless of the estimation method, owning a digester is associated with a statistically significant and economically substantial reduction in annual energy expenditures. In absolute terms the savings amount to about 56,000 RwF per year or a 31 percent reduction in annual energy expenditure as compared to applicant households. The main source of savings is a 35,000 RwF reduction in annual expenditure on firewood. Cost savings on charcoal are about half that amount. With regard to fuel use, owing a digester is associated with a 5 kilogram reduction in daily consumption of firewood. Consumption of charcoal also declines but the effect is not statistically significant.[16] The estimates displayed in Table 10 may be interpreted as the average effect of participating in the NDBP. The similarity between estimates based on differences in means and OLS/PSM approaches enhances the claim that the sampling approach has been successful in delivering a comparable control group. Estimates after dropping households with non-functioning digesters are in Table A4. As may be expected the energy savings generated by a digester conditional on functioning are larger - annual energy savings amount to 91,633 RwF and reductions in the consumption of firewood and charcoal are also more pronounced. These estimates should be interpreted as the effect of access to biogas or as the potential impact of the NDBP programme if all the installed digesters had been functioning.

[14] 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 daily usage of fuel wood or did not have any in stock at the time of the visits.

[15] 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 a surprise given the similarities between the treated and control households. Estimates of the probit model used to obtain the propensity scores are provided in Table A3.

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

While the focus of the paper is on the impact of digesters on energy expenditure and fuel use we also examined impacts on other outcomes, in particular, time-use patterns, kitchen environment and sanitation practices. Possessing a digester may be expected to reduce the time spent on gathering/foraging for wood and time spent on cooking. As shown in Tables 12 and 13, while there is a reduction in time spent on gathering firewood the effects are statistically significant only for time spent on cooking. Time spent on cooking in digester-owning households is 31 to 37 minutes less per day (an 18 percent reduction) as compared to applicant households. This is a large effect but is matched by an increase in time spent on running the digester (see Table 12).

There is a large (28 percentage point effect) difference in women's perceptions of their cooking environment (see Tables 13 and 14). While 85 percent of women without digesters mentioned that their kitchens were always or sometimes smoky, the figure falls to 56 percent for owners. Furthermore, digester owning households are about 8 percentage points more likely to always boil water for drinking purposes and 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). While such conditions may translate into health benefits, given the duration of the program, such an examination is premature.

6. Financial benefits and payback period

As discussed in Section 2, despite the feasibility reports which indicated that there was ample scope for developing a biogas programme and the subsidies provided to purchase a digester, uptake has been far lower than expected. A closer look at the costs of purchasing a digester, the functioning of the programme and the financial benefits that the programme yields helps explain the slow uptake.

Based on our field experience, there appear to be two main issues responsible for the refraction between plans and uptake. These are the price of a digester and the lack of proper functioning of a portion of completed digesters.[17] The feasibility study, perhaps based on experiences in Asia, pegged the cost of a 6m^3 digester at about 260,000 RwF, while the actual price turned out to be 800,000 RwF or triple the original estimate. 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) (see Table 3). Even though it is possible for owners to lower their financial disbursement, by about 140,000 RwF, through contribution of 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.[18] Without the subsidy the cost of the cheapest digester amounts to 2.6 times annual per adult equivalent expenditure. In addition, as discussed in the preceding sections, concerns about costs are compounded with concerns about the actual functioning of the digesters.

To assess whether investing in a digester is worthwhile we use the estimates provided in Tables 11 and A4 to provide a payback analysis for a 6m^3 digester. Our measure of benefits only includes costs savings and not potential health and environmental benefits.[19] This is an admittedly narrow but nevertheless useful assessment. We provide payback periods for situations where (i) a subsidy is provided or not and (ii) including all digester owners and restricting the assessment to digester owners with functioning digesters.

The analysis presented in Table 15 (estimates with discounting) shows that without the subsidy, on average, a digester owner participating in the programme may expect a payback in about 30 years. This is clearly too long as compared to the 20 year expected lifespan of a digester.

[17] 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.

[18] 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.

[19] We also investigated the impact of owning a digester on fertilizer expenditures and increase in agricultural productivity. There were no statistically significant effects.

With the subsidy the payback period falls to about 13 years. If all the digesters that have set up by the programme were working as expected then the payback period *without* a subsidy would be about 13 years and with a subsidy about 7 years. Clearly, the subsidy plays a large role in reducing the payback period. However, the same payback period may be reached without a subsidy if all the digesters had been functioning.

7. Concluding remarks

This paper analysed the effect of Rwanda's National Domestic Biogas Programme (NDBP) on energy expenditure and fuel use. In doing so it adds to the thin literature which has examined the effects of such initiatives in a systematic manner. Methodologically, the paper improves on the existing body of work by providing estimates based on a relatively larger sample size and careful construction of a control group from amongst potential applicants - that is, those who displayed an interest in acquiring a digester and met the eligibility conditions needed to purchase a digester.

Regardless of the estimation approach, we found that owning a digester is associated with a 30 percent reduction in annual energy expenditure and a 5 kilogram or 30 percent reduction in daily consumption of firewood. These are large effects. Despite these benefits and feasibility studies which highlighted the favourable conditions for such a program, by the end of November 2012 only about 15 percent of the original ambitions of setting up 15,000 digesters had been met. While there may be several reasons for the slow programme uptake, the two main issues revealed by our analysis are the price of a digester and the inadequate functioning of completed digesters. With regard to the former issue, the price of acquiring a 6 cubic metre digester is 800,000 RwF which is three times higher than the price which was used in the feasibility studies and about 2.6 times the annual per adult equivalent consumption in rural Rwanda. Not surprisingly, the average household in our biogas sample is substantially more prosperous than the average household in rural Rwanda. Added to the cost are issues related to the functioning of digesters with 10 percent of the supposedly completed digesters producing no gas. An assessment of the reduction in energy expenditure generated by the digesters versus the cost of purchasing a digester yields a payback period of 30 years in the absence of a subsidy and 13 years with a subsidy. Given the anticipated 20 year lifespan of a digester it is unlikely that in its current form the program is viable without a subsidy.

Immediate measures may be taken to enhance the attractiveness of the program: ensuring that all the completed digesters are actually functioning and attaining a better match between the cattle holdings of a household and its digester size. In the longer-term if biogas is to reach a substantial proportion of the potential target group of close to 300,000 cow-owning households then the cost of a digester needs to be substantially lower. At the moment the programme relies on a digester adapted from Nepal. However, a promising technical development is that a local technical college has been working on the design of new digester models. These models which have been developed specifically for the Rwandese market use less concrete and rely on burnt bricks. Such innovations are expected to lead sharp reductions in price. Indeed, without a reduction in price it is hard to see how biogas can go beyond being a niche energy source in Rwanda.[20]

[20] According to SNV Rwanda, Tumba Technical College is developing locally suited models. 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.

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Table 1: Main source of energy for domestic purposes, 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
Other	1.5	3.4	1.5	5.9	5.9	3.4	1.3	3.6

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

Table 2: Projected installation of digesters

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Phase	Preparation phase		Implementation phase			
Number of digesters [a] (projected)	150	1,150	2,300	4,200	7,200	15,000
Year	**2007-2009**	**2010**	**2011**	**2012**	**Total**	
Number of digesters [b] (installed)	366	627	755	699	2,447	

Source: [a] Dekelver (2008); [b] NDBP (data are current up to the end of November 2012)

Table 3: Size of digester, costs and subsidy provided (in RwF)

Size	**Cost of plant**	**Subsidy**
$4m^3$	350,000	300,000
$6m^3$	500,000	300,000
$8m^3$	650,000	300,000
$10m^3$	800,000	300,000

Source: NDBP

Table 4: Descriptive Statistics - Means (Standard Deviation)

	Total	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ *p*-values
HH (household head) is male (in percent)	83.7	84.6	82.7	0.53
	(0.37)	(0.36)	(0.38)	
Age of the head of the household	48.3	48.9	47.7	0.17
	(11.0)	(11.5)	(10.5)	
Household size	6.3	6.5	6.2	0.25
	(2. 6)	(2.7)	(2.5)	
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	8.01	7.0	0.00***
	(4.13)	(4.33)	(3.86)	
Number of years of schooling of spouse of HH[a]	6.4	6.3	6.4	0.97
	(3.03)	(3.14)	(2.94)	
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
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	96.4	92.9	0.06*
	(0.22)	(0.18)	(0.25)	
Size of cultivated land (in ha.)	2.2	2.4	1.9	0.01***
Livestock ownership				
Households has 2 or more cows (in percent)	94.5	93.77	95.2	0.42
	(22.81)	(24.20)	(21.29)	
Cow (milking, non-milking and calves)	5.3	5.6	4.9	0.14
	(6.3)	(6.2)	(6.4)	
Pig	0.9	0.6	1.1	0.48
	(7.5)	(4.2)	(11.7)	
Sheep and goats	1.5	1.5	1.6	0.91
	(5.7)	(3.4)	(6.7)	
Poultry and rabbit	5.1	4.1	6.0	0.23
	(19.8)	(15.3)	(23.2)	
Per capita annual consumption (in RwF)[a]	282,117	291,177	273,026	0.61
	(426,954)	(363,308)	(482,968)	
Number of observations	**600**	**305**	**295**	

Notes: *, **, *** significant at 10, 5, 1 percent, respectively. [a] Statistics on per capita yearly expenditure include 559 households (280 digester owners and 279 potential applicants).

Table 5: Amount of cow dung and water used to feed digesters and numbers of cows owned

Size	Cow dung (kg)	Water (litres)	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: The daily feeding requirements to operate a 4 m3 digester are 30 kilos of cow dung and 30 litres of water; for a 6 m3 digester 50 kilos and 50 litres; for an 8m3 digester 70 kilos and 70 litres; for a 10m3 digester 90 kilos and 90 litres. On average, each adult cow produces 16-20 kg of dung per day.

Table 6: 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*		
4m3	0	1	55		
	0 cows	*1 cow*	*2 cows*	*3 or more cows*	
6m3	10	6	34	139	
	0 cows	*1 cow*	*2 cows*	*3 cows*	*4 or more cows*
8m3	0	0	3	7	28
	0 cows	*1 cow*	*2 cows*	*3 cows*	*4 cows*	*5 or more cows*
10m3	0	0	0	1	3	15

Table 7: Household budget shares based on annual expenditure

Expenditure	**Entire sample**	**Digester owners**	**Potential applicants**	***H₀*: $X_{DO} = X_{PA}$ *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). *, **, *** significant at 10, 5, 1 percent, respectively.

Table 8: Average annual expenditure on main energy sources (standard deviation in parentheses), in RwF

	Digester users	**Digester 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). 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, 5, 1 percent, respectively

Table 9: Total amount of fuel consumed per day (standard deviation in parentheses), in kilograms

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ **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)	

Note: Statistics are based on 305 digester owners and 295 potential applicants. *, **, *** significant at 10, 5, 1 percent, respectively

Table 10: Impact of program participation on annual energy expenditures and daily fuel consumption (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Yearly exp. on energy (RwF)					
Digester owner	-56,426**	-57,774***			
	(27,037)	(22,786)			
N	597	595			
R^2	0.060	.			
Yearly exp. on firewood (RwF)			*Yearly exp. on charcoal (RwF)*		
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 firewood (in kg.)			*Daily consumption of charcoal (in kg.)*		
Digester owner	-5.11***	-4.71***	*Digester owner*	-.40	-0.36
	(1.06)	(1.27)		(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. *, **, *** significant at 10, 5, 1 percent, respectively

Table 11: Time use (standard deviation in parentheses)

	Digester owners	Potential applicants	H_0: $X_{DO} = X_{PA}$ ***p*-values**
Time spent on collecting/buying fertiliser (minutes per day)	5 (4.52)	4 (3.95)	0.53
Time spent on gathering/acquiring firewood (minutes per day)	37 (123.01)	42 (114.97)	0.61
Time spent cooking (minutes per day)	144 (77.50)	175 (70.43)	0.00**
Time spent on fetching water (minutes per day)	70 (174.38)	56 (83.43)	0.35
Time spent operating (fill water and dung, mix, check) a digester (minutes per day)	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. *, **, *** significant at 10, 5, 1 percent, respectively

Table 12: Impact of digesters on time use (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Time spent cooking (minutes per day)			*Time spent gathering fertiliser (minutes per day)*		
Digester owner	-31.63*** (8.91)	-37.25*** (6.77)	*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 (minutes per day)			*Time spent fetching water (minutes per day)*		
Digester owner	-4.65 (6.54)	-6.03 (11.05)	*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. *, **, *** significant at 10, 5, 1 percent, respectively.

Table 13: Cooking environment and sanitation

	Total	Digester owners	Potential applicants	***H_0***: $X_{DO} = X_{PA}$ ***p*-values**
Smoke in the kitchen				
Yes, always	45.6	18.7	73.7	0.00***
Yes, sometimes	24.9	37.7	11.6	0.00***
Household always boils water before consumption	77.0	82.3	71.5	0.78
Number of times a stove is used per week for heating bath water	6.5 (2.3)	6.7 (2.1)	6.2 (2.3)	0.01***
Number of times a stove is used per week to boil water to clean milk cans	7.0 (2.1)	7.3 (2.4)	6.7 (1.7)	0.00***

Notes: *, **, *** significant at 10, 5, 1 percent, respectively.

Table 14: Impact of digesters on cooking environment and sanitation

Variable	**Probit**	**PSM**
Smoke in the kitchen		
Digester owner	-0.28*** (0.03)	-0.25*** (0.03)
N	597	595
Pseudo R^2	0.142	.
Households boil water before consumption	0.077**	0.062
Digester owner	(0.034)	(.039)
N	597	598
Pseudo R^2	0.140	0.034
	OLS	**PSM**
Number of times a stove is used per week for heating bath water		
Digester owner	0.505*** (0.170)	0.461* (0.246)
N	411	409
R^2	0.125	0.033
Number of times a stove is used per week to boil water to clean milk cans		
Digester owner	0.508*** (0.264)	0.581*** (0.621)
N	450	447
R^2	0.094	0.029

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. *, **, *** significant at 10, 5, 1 percent, respectively,

Table 15: Payback analysis for a 6 cubic metre digester

Without discounting	**Cost of the digester**	**Digester owners**	**Digester owners with functioning digesters**
Cost without subsidy (RwF)	800,000		
Cost with subsidy (Rwf)	500,000		
Benefit - annual reduction in energy expenditure (RwF)		57,744	91,633
Payback period without subsidy		13.8 years	8.7 years
Payback period with subsidy		8.7 years	5.4 years
With discounting			
Cost without subsidy (RwF)	800,000		
Cost with subsidy (Rwf)	500,000		
Benefit - annual reduction in energy expenditure (RwF)		57,744	91,633
Payback period without subsidy		30.5 years	12.7 years
Payback period with subsidy		12.6 years	6.8 years

Notes: The analysis is based on a 6m3 digester as 60 percent of households have a digester of this size. Calculations do not include the costs of servicing loans as the bulk of households (62 percent) finance the purchase using their own resources; maintenance costs are assumed to be zero. 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. 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).

Table A1: 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*

Table A2: 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

Table A3: 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)
Pseudo R^2	0.039	0.034
Number of observations	556	597

Notes: *, **, *** significant at 10, 5, 1 percent, respectively.

Table A4: Impact of owning a functioning digester on annual energy expenditures and daily consumption (standard errors in parentheses)

Variable	OLS	PSM	Variable	OLS	PSM
Yearly exp. on energy (RwF)	-82,581***	-91,633***			
Digester owner	(17,034)	(18,351)			
N	569	567			
R^2	0.14	.			
Yearly exp. on firewood (RwF)	-59,258***	-66,861***	*Yearly exp. on charcoal (RwF)*		
Digester owner	(14,295)	(15,626)	*Digester owner*	-17,081***	-13,893***
				(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	.

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. *, **, *** significant at 10, 5, 1 percent, respectively.