Energy Economics 68 (2017) 66–76

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

The impact of a household biogas programme on energy use and expenditure in East Java

Arjun S. Bedi [a,*], Robert Sparrow [b,c], Luca Tasciotti [b,d]

[a] International Institute of Social Studies, Erasmus University Rotterdam, Kortenaerkade 12, 2518, AX, The Hague, The Netherlands
[b] Erasmus University Rotterdam, The Netherlands
[c] Wageningen University, The Netherlands
[d] School of Oriental and African Studies (SOAS), United Kingdom

ARTICLE INFO

Article history:
Received 18 November 2016
Received in revised form 23 May 2017
Accepted 18 September 2017
Available online 27 September 2017

JEL classification:
Q40
Q42
Q48

Keywords:
Energy policy
Renewable energy
Biogas
Indonesia

ABSTRACT

Biogas has been promoted as a renewable, cleaner and cheaper energy source. While there are several initiatives promoting the use of biogas, credible analyses of its effects on the use of alternative energy sources and energy related expenditure are limited. This study uses panel data from households engaged in dairy farming in rural East Java to assess the impact of a household level programme, which promotes the construction of digesters that produce biogas, on energy use and expenditures. Both a difference-in-difference analysis and a pipeline comparison show that the use of digesters leads to a sharp reduction in energy related expenditures and a reduction in the use of firewood and liquefied petroleum gas. However, without subsidies, the payback period of between 11 and 14 years, albeit based only on reductions in energy costs accruing from investing in a digester, is perhaps too long to justify the investment.

1. Introduction

In a number of developing countries, biogas has been promoted as a renewable, cleaner and cheaper energy source, especially for cooking, as compared to alternatives such as firewood and kerosene. For instance, countries such as China and India have a long history of promoting biogas. However, it is only in the last twenty five years that household level biogas programmes, which promote construction of digesters or tanks which convert organic waste into biogas, have spread across the globe.[1] According to Rakotojaona (2013), >250,000 digesters have been installed in Nepal since 1992 and about 125,000 in Vietnam in 2003. Other Asian countries with household biogas programmes include Cambodia and Bangladesh which launched their biogas programmes in 2006 and most recently, Pakistan and Indonesia in 2009.[2]

In the Indonesian context, while a majority of the population has access to electricity for lighting, biomass, mainly wood, remains an important energy source for cooking (see Table 1). At the national level, in 2011, for 40% of Indonesian households, firewood was their primary cooking fuel, while in East Java, 43% of households relied mainly on firewood for cooking and about 52% used liquefied petroleum gas (LPG). The substantial use of LPG is relatively new and is a consequence of the country's large-scale kerosene to LPG conversion programme (2007–2012) which was motivated by a desire to reduce the budgetary burden of the kerosene subsidy.[3] Despite the conversion programme and other reforms which have reduced the subsidy burden, the growth in energy demand combined with declining domestic production and an increase in fuel imports continues to ensure that subsidies for oil-based fuels remain a large burden on the budget (see Asian Development

* Corresponding author.
E-mail addresses: bedi@iss.nl (A.S. Bedi), robert.sparrow@wur.nl (R. Sparrow), lt20@soas.ac.uk (L. Tasciotti).

[1] The main element of a biogas digester is a tank in which bacteria converts organic waste into biogas through a process of anaerobic digestion.

[2] A number of African countries have also launched household biogas programmes. Rwanda launched its national domestic biogas programme in 2007, followed by Cameroon, Ethiopia, Kenya, Tanzania and Uganda in 2009 and Burkina Faso, Benin and Senegal in 2010. See Hessen (2014) for details.

[3] Based on the view that ensuring access to energy is the responsibility of the state, the Indonesian government provides energy at subsidized prices to its citizens. Between 2001 and 2008, energy subsidies accounted for 9 to 18% of total public expenditure. In 2006, before the launch of the kerosene to LPG conversion programme, kerosene accounted for 57% of the total subsidy for petroleum products or about USD 3.64 billion (see PT Pertamina and WLPGA, 2012).

https://doi.org/10.1016/j.eneco.2017.09.006
0140-9883/

Table 1
Access to electricity and energy for cooking in sampled districts in East Java, in percent.

	Sampled districts	East Java	National
Use electricity for lighting (%)	99.24	99.49	95.43
Primary energy source for cooking (%)			
Electricity	0.85	0.90	0.98
LPG	52.28	51.67	46.78
Kerosene	1.30	3.55	11.18
Firewood	44.92	43.09	39.60
Other	0.64	0.80	1.48

Source: Indonesian Socioeconomic survey 2011, own computation.

Bank, 2015; International Institute for Sustainable Development, 2011).[4]

At the same time as attempting to reduce the subsidy burden through the conversion programme the government passed a number of decrees and acts which recognized the importance of promoting and developing alternative energy sources and technologies, both from an environmental and a budgetary perspective (see SNV, 2009). Specifically, a presidential decree (No.5/2006) on National Energy Policy released in January 2006 stated the government's goal of ensuring security of energy supply by reducing the share of oil-based fuels in the country's energy mix from 51% in 2006 to 20% in 2025, primarily by increasing the share of renewable energy.

Specifically with regard to biogas, mainly due to the widespread availability of firewood and heavy subsidies for kerosene, its use in Indonesia has been limited. However, since 2005, following the reduction of kerosene subsidies and consistent with the National Energy Policy of reducing reliance on oil-based fuels, various institutions and organizations began developing activities to disseminate manure fed biogas digesters. By the end of 2009, through fifteen initiatives about 6000 digesters had been installed for domestic use (SNV, 2009). To consolidate these scattered efforts and to boost the spread of biogas, in 2009, the Indonesian government launched a Household Biogas Program (*Programme Biogas Rumah* – BIRU). The key objective of the programme was to install 8000 digesters by 2012 in rural dairy farming households located in eight provinces. The focus of the program was on East Java. The program operates through dairy cooperatives and is voluntary. Dairy farmers who fulfil eligibility conditions such as ownership of at least two cows and who have an established record of delivering milk to a cooperative are offered a chance to purchase a digester. An innovative aspect of the BIRU program is its co-operation with international companies, which makes it easier for dairy farmers to access credit.

Similar to biogas programs in other countries, the expectation is that the use of biogas will generate immediate benefits by reducing the use of traditional fuels and energy-related expenditures, as well as lead to time-savings due to a reduction in time spent gathering wood. 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. Despite these expectations and the large number of initiatives in a number of Asian and African countries (see Rakotojaona, 2013; Hessen, 2014), credible evidence on the actual impacts of such household biogas programs on short-term outcomes such as use of traditional fuels and energy-related expenditures as well on longer-term outcomes such as agricultural productivity and health outcomes is limited. The bulk of the evidence is based on either before-after comparisons or single-period comparisons between households with and without a digester.

For instance, based on a before-after comparison of a sample of 461 biogas users in Nepal, Katuwal and Bohara (2009) report a 53% reduction in the use of firewood and an 81% reduction in the time spent collecting firewood. Employing a similar approach but working with a sample of only 12 users, Garfí et al. (2012) report a 50 to 60% reduction in the use of firewood. Despite these effects, the lack of a control group hampers the credibility of the analysis.

Alternatively, based on single-period comparisons between 615 biogas users and 740 non-users drawn from 133 villages, a study of India's National Biogas Development Project (Program Evaluation Organisation, 2002) found that a majority of digesters (55%) were not operational. Nevertheless, user households reduced their monthly consumption of firewood by 10 kg. 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 had only partly been realized, if at all. For most of the outcomes there were no statistically significant differences between users and non-users. In both these studies the approach used to determine the control group was not clear and assessments were based on differences in means, without controlling for variables which might influence both uptake of digesters and outcomes.[5]

A perhaps more rigorous assessment of the effect of a biogas initiative, Rwanda's National Domestic Biogas Program (NDBP), is provided by Bedi et al. (2015). While their study also uses cross-section data and compares outcomes for users and non-users, the non-users were selected from a list of “potential applicants” that is, those who had shown an interest in purchasing a digester and at the same time the non-users needed to fulfil the most important eligibility condition to become a user, that is, own at least two cows. Their multivariate analysis showed that owning a digester was associated with a 31 to 32% reduction in annual energy expenditure and a five kilogram or 34% reduction in daily consumption of firewood. At the same time they reported that about 10% of the supposedly completed digesters were producing no gas, and that the cost of installing a digester was prohibitive leading to a large gap between the number of digesters that were expected to be set up (15,000) and the number that were actually installed (1800).

The aim of this paper, which focuses on dairy farmers in East Java, is to examine the impact of Indonesia's Household Biogas Program (BIRU) on two main outcomes, that is, fuel use - whether access to digesters leads to reductions in the use of an oil-based fuel - liquefied petroleum gas and the use of a traditional fuel - wood, and whether it leads to a decline in energy-related expenditure. In order to assess the viability of the intervention we provide an exploratory payback analysis. Methodologically, the paper extends the literature by using multiple evaluation strategies and providing estimates based on both cross-section and panel data. In doing so, we attempt to place the literature on the effects of household biogas initiatives on a stronger empirical footing.

The paper is structured as follows. Section 2 contains a description of the program. Section 3 outlines the empirical approach, Section 4 lays out the sampling strategy and discusses the data and descriptive statistics. Section 5 discusses the findings and presents a payback analysis while Section 6 concludes.

[4] The conversion programme was rolled out successfully and by 2009 large parts of the country including all of East Java had been covered by the programme. With regard to the subsidy, in 2011, the kerosene subsidy amounted to USD 1 billion while the LPG subsidy amounted to USD 2.11 billion.

[5] Laramee and Davis (2013) work with a small sample of 40 households (20 users and 20 non-users) and conclude that in Tanzania, biogas almost completely replaces the use of firewood and kerosene. While the effects in this case are in marked contrast to the papers on India and China, the estimates are based on a much smaller sample and the control group was identified by asking user households to nominate a control rather than through an objective approach.

2. Indonesia's household biogas program – Key features

In 2008, the Government of Indonesia in co-operation with the Government of the Netherlands commissioned a feasibility study. The study highlighted that the climatic conditions, especially high temperatures throughout the year and availability of water, provided a favourable environment for the production of biogas. The report pegged the number of potential digesters users at more than one million dairy farming households in Java and Bali, where zero grazing is widely practised (SNV, 2009).[6]

In 2009, as a consequence of the feasibility study, Indonesia launched a Household Biogas Program (BIRU).[7] BIRU's overall objective is to disseminate domestic digesters in order to create a local, sustainable energy alternative. The program set itself a target of installing 8000 family sized (plant sizes of 4, 6, 8, 10 and 12 m^3) digesters in eight Indonesian provinces (East Java, DIY Yogyakarta, Central Java, West Java, Bali, West Nusa Tenggara, South Sulawesi and Lampung) by the end of 2012. Although the programme had a slow start, it soon picked up momentum. By May 2011 the target for 2011 had already been achieved, with over 2700 installed digesters and over 900 applicants awaiting construction of a digester. By the end of 2012, it had met its target of disseminating about 8000 biogas digesters (see Table A.1). The BIRU program focuses mainly on East Java (62% of all digesters), followed by Lombok/Bali (17%), West Java (10%) and Central Java (9.6%) (see Table A.2).

BIRU carries out its work through intermediaries or so-called, Construction Partner Organizations (CPOs) and biogas supervisors. Typically, the CPOs are co-operative organizations or local NGOs. In Java, dairy co-operatives are key partners in the BIRU programme and help disseminate the biogas concept among dairy farmers. The CPOs raise awareness about biogas among their members in their regular meetings or in special gatherings explicitly for the purpose of discussing this issue. If members show interest, the CPO carries out a farm eligibility assessment, which is based on criteria such as having at least two cows, a positive cash flow from milk revenues supplied to the co-operative, and a farmer's debt history. In addition, the CPO verifies whether the farm plot is large enough to install a digester. If a farmer qualifies, financial arrangements are negotiated with the help of the CPO, and subsequently masons trained by BIRU are deployed to construct the digesters.[8] After the digester has been installed, the mason files a completion report, and BIRU carries out quality control checks. BIRU trains dairy farmers on the proper usage of digesters. They receive a user manual and a mason is present during initial plant feeding. BIRU guarantees an after sale service of two years.[9]

Depending on the size, the cost of a digester lies between €450 and €700. Regardless of the digester size, BIRU provides a flat subsidy of €160 (Table 2). The remainder is paid by the farmer, usually through a loan obtained from credit schemes offered by the cooperative. The repayment instalments are financed by deductions from payments the farmer receives for the delivery of milk. Interest rates differ across cooperatives, depending on the source of the loan. A range of partners have made resources available for the credit schemes, and while there are no interest charges on 2 to 3 year loans provided by Nestlé, an international food company, other partners such as Rabobank or Bank Syariah Mandiri (BSM) charge interest rates of 8 to 11% with repayment periods of 3 to 5 years.

Table 2
Size of digester, costs and subsidy provided.

Size of the digester plant	Cost of the plant for the user (Indonesian Rupiah)	Subsidy provided (Indonesian Rupiah)
4 m^3	3,700,000	2,000,000
6 m^3	4,300,000	2,000,000
8 m^3	5,000,000	2,000,000
10 m^3	6000,000	2,000,000
12 m^3	6,800,000	2,000,000

Source: Bedi et al. (2013) *Note*: One Euro = IDR 12,500.

3. Identifying the impact of digesters

Our main aim is to identify the extent to which changes in the main outcomes of interest - in this case, fuel use and energy expenditure may be attributed to the BIRU programme. To identify these effects, the evaluation relies on both cross-section and panel data and a comparison between farm households with (treatment group) and without (control group) a digester. There are two main empirical concerns with regard to attribution. First, the program is voluntary and households need to take the initiative to apply for a digester and second, conditional on application, program beneficiaries are not selected at random but need to fulfil eligibility conditions such as ownership of at least two cows and a regular record of delivering milk to a cooperative. Due to these two aspects – self-selection into the program and the imposition of eligibility conditions – it is quite likely that those who apply and obtain a digester are systematically different from those who do not. Hence, comparisons between households who have a digester and those who don't, without accounting for potential differences in factors that determine selection into the program are unlikely to yield credible estimates.[10]

To account for the challenges highlighted in the preceding paragraph and to deliver credible estimates, the study relies on two different evaluation approaches, that is, difference-in-differences (DID) estimation and a pipeline comparison design, both of which we combine with propensity score matching (PSM). For the DID analysis we rely on baseline (2011) and follow-up (2012) data on the same set of dairy farmers. We compare outcomes for farming households (h) who acquired a digester through BIRU between baseline and follow-up with outcomes for farming households (h) who did not obtain a digester between 2011 and 2012. The differences in outcomes (y_{ht}), over time (t), that is, between baseline and follow-up and between BIRU participants ($D_{2012}=1$) and non-participants ($D_{2012}=0$), may be interpreted as the causal effect of the BIRU biogas digesters. The DID estimates may be written as:

$$\Delta_{DD} = E(y_{h,2012} - y_{h,2011} | D_{2012} = 1) - E(y_{h,2012} - y_{h,2011} | D_{2012} = 0). \quad (1)$$

The causal interpretation is based on the (parallel trends) assumption that changes in outcomes recorded for the control group are similar to the changes in outcomes that would have been observed for the BIRU participants had they not had a biogas digester installed. By comparing differences in trends across treatment and control groups, rather than differences in levels, this approach eliminates time-invariant unobserved differences such as the latent ability and productivity of farmers which

[6] Zero grazing implies that cows are not put out to pasture but instead food is brought to the cows. This makes it easier to gather and use cow dung.

[7] It is a four-year programme funded by the Royal Netherlands Embassy and implemented by Hivos with the Ministry of Energy and Mineral Resources (MEMR) of the Republic of Indonesia and with the technical assistance of SNV. Among other tasks, Hivos and SNV are responsible for effective knowledge exchange and transfer during the implementation of the programme. Information available from http://www.biru.or.id/en/index.php/biru-program/, last accessed on May 8th, 2017.

[8] Since programme inception, BIRU has trained 675 masons and 124 supervisors. The intention is that in the long-term, the training will be taken over by local institutions such as technical and vocational schools. To select masons BIRU requires that they should: i) be from the area where the digesters are to be constructed ii) have sufficient experience in brick laying and plastering iii) be able to read, write and to understand drawings.

[9] Specifically, in East Java, the BIRU programme is active in nine rural districts and involves 11 CPOs. These CPOs serves one to three dairy cooperatives. Each of the 19 involved cooperatives has a biogas supervisor who disseminates information about the BIRU programme and the eligibility criteria. The supervisor also manages the credit schemes.

[10] For instance, the (latent) ability and productivity of household members, their risk taking ability, their willingness to adopt modern technology and other unobserved factors may affect the probability of applying for a digester and this may also have an effect on the outcomes of interest.

Table 3
Treatment and control groups, by evaluation strategy.

Sample	Definition	Pipeline comparison Cross-section 2011	Difference-in-difference Panel 2011-2012
Always users	Have fully operational biogas digester installed at the time of baseline survey in 2011 ($D_{2011}=1, D_{2012}=1$)	Treatment group	
New users	Have fully operational biogas digester installed at the time of follow-up survey in 2012, but had no biogas digester in 2011 ($D_{2011}=0, D_{2012}=1$)	Control group	Treatment group
Never users	Do not have a biogas digester in 2011 or 2012 ($D_{2011}=0, D_{2012}=0$)		Control group

may have a bearing on digester uptake and outcomes. In order to enhance the credibility of the basic DID analysis and to ensure comparability of the treatment and control group in terms of observed characteristics we combine the basic DID analysis with propensity score matching. Using this approach, each unit in the participant group is matched to an observationally similar unit from the non-participant group. This procedure implies that the control group is re-weighted such that it appears identical to the treatment group in terms of observed characteristics. Subsequently, DID analysis/pipeline comparison is conducted on the treated units and the matched controls.[11]

While the combination of PSM and DID allows us to control for differences in observed characteristics between the treatment and control groups as well as to control for time-invariant differences in unobserved characteristics that may be correlated with programme uptake and outcomes, the credibility of the estimates is based on the validity of the parallel trends assumption. The main threat to this assumption is if participation in – or targeting of – the BIRU program is determined by shocks to the outcome variables (for example, poverty and social safety net programs), or if inherent unobserved differences between treatment and control groups induce different outcome trajectories in the absence of the program. There are several reasons why the nature of the BIRU program is likely to reduce these threats. First, participation in the BIRU program is not driven by shocks or unexpected events. Rather, these are long-term investment decisions by farm households, with assistance from BIRU CPOs. Second, the analysis focuses on a relatively homogeneous group of farmers who operate in a similar production and institutional context and it is unlikely that time-varying shocks have different effects on outcomes across the treatment and control group.

Nevertheless, in addition to the difference-in-difference analysis we also consider a cross-section based pipeline comparison approach. This method exploits a particular feature of the BIRU program, which is that the program was rolled out gradually over a 4-year period. This means that during the baseline survey, some farmers without a digester had already applied for a digester and were awaiting delivery. That is, in 2011 they were in the pipeline to be treated in 2012. These farmers can be readily identified in the survey waves as the new users of biogas digesters in 2012. To implement the pipeline evaluation design we use these digester applicants or future users as a control group in the baseline year and compare them with farmers that were already participating in the BIRU program in 2011. The pipeline comparison estimates may be written as:

$$\Delta_P = E(y_{h,2011}|D_{2011}=1, D_{2012}=1) - E(y_{h,2011}|D_{2011}=0, D_{2012}=1) \quad (2)$$

This approach addresses potential bias due to eligibility or self-selection as both the groups have shown a desire to purchase a digester. In addition, this approach does not rely on the parallel trends assumption. However, the cross-sectional pipeline comparison introduces other problems. For example, there may be systematic differences between early and late adopters of an innovative technology, a problem that difference-in-difference analysis can deal with more effectively. Thus, while this approach is not a substitute for the difference-in-difference analysis, it does provide an alternative evaluation methodology that allows us to evaluate the robustness of the results. Similar to the difference-in-difference analysis, we combine the cross-section based pipeline comparison approach with propensity score matching in order to enhance comparability of the treatment and control groups.

To enhance clarity, Table 3 summarises the choice of treatment and control groups for the different evaluation strategies. For the difference-in-difference evaluation, two groups of households are compared. First, the treatment group consists of households that did not have a biogas digester in 2011 but did have one in 2012. We refer to them as *new users* in the subsequent sections. Second, the control group consists of farm households with comparable features (e.g. members of a cooperative, reside in the same villages, same number of productive cows) but those who have never obtained a biogas digester. We refer to them as *never users* in the following. For the cross-sectional pipeline comparison approach, a second treatment group is defined as consisting of households who were already using biogas digesters, whom we refer to as *always users*. In this approach, the *new users* (i.e., the first treatment group) serve as a cross-sectional control group.

4. Sampling strategy and the data

4.1. Sampling

The evaluation is based on two survey rounds of the same households conducted in May-June 2011 and May-June 2012 in East Java province. In addition, qualitative information was acquired using focus group discussions and key informant interviews. East Java was chosen as at the time of the first survey it contained >75% of the digesters installed through the BIRU program. In 2011, the BIRU program was active in 9 rural districts in East Java and involved 11 CPOs. Given budgetary considerations the overall sample size was set at 700 households, consisting of 250 applicants (*new users*), 350 non-applicant households (the potential *never users*) and 100 households with a digester (*always users*).[12]

Dairy farmers participating in the CPOs/cooperatives covered by the BIRU program form the natural sampling frame from which to draw treatment and control groups. Accordingly the first step in the sampling procedure involved the selection of CPOs to be included in the survey. Two CPOs were dropped as they only had a small number of installed digesters which left us with 9 CPOs.

In the second step we obtained a list of applicants, non-applicants and current users from each of the 9 CPOs. The list included 497 applicants, 18,321 non-applicants who satisfied certain conditions and 2086 current users. We began by drawing a random sample of 250

[11] A logit specification where the probability of participating in the BIRU program is treated as a function of baseline characteristics is used to predict the propensity score. Five nearest-neighbor matching is used to create a set of treated and matched controls.

[12] Power calculations (setting alpha = 0.05 and beta = 0.8) suggest that this sample size (treatment and control samples of 350 and 250 households) is sufficient to detect reasonable effect sizes (standardized effect size of 0.25) for the main outcome variables (firewood/LPG consumption and energy expenditure).

Table 4
Composition of 2012 treated and controls.

Status in 2012	Sampling group in 2011			Total sample
	Always users	Applicant	Control	
Always users	97			97
New users		184	32	216
Never users		61	303	364
Total sample	97	245	335	677

Source: BIRU project data; Cooperative members' lists.

applicants. The distribution of the sample across CPOs was based on the relative share of the applicants in each CPO. Turning to the non-applicants, in order to serve as suitable controls, non-applicants had to comply with three conditions. They had to have at least one productive cow, had to regularly supply milk to the cooperative and should not already own a digester provided through a different program. From the set of 18,321 potential controls, 344 were randomly selected. Finally, 101 users were randomly drawn from the set of existing users. In the case of both non-applicants and existing users, the distribution of the sample across each CPO was proportional to the underlying distribution of the population.[13] A total of 695 households were surveyed at baseline.

In 2012, we attempted to survey the same households. We were unable to locate 18 households at follow-up. Our statistical assessment shows that there is no systematic difference between those who remained in the sample and those who dropped out.[14] A potentially more serious sampling problem is non-compliance with user status. After accounting for attrition, of the 245 applicants who were expected to obtain digesters in 2012, 61 had their applications rejected by BIRU and remained in the *never user* category. At the same time, of the 335 individuals who were designated as controls in 2011 and surveyed again in 2012, 32 secured a digester between the baseline and follow-up period. We have assigned these non-compliers to the groups we find them in 2012, that is, 97 *always users*, 216 *new users* and 364 *never-users* (Table 4).

In the case of the pipeline comparison design which is based on comparing *always users* with applicants the analysis focuses on the 97 *always users* and the 216 *new users* who were either applicants (184) or part of the control group (32) in 2011. Since the *always users* and the *new users* have both been accepted by the BIRU programme, it may be argued that dropping the non-eligible applicants and focusing on *always users* and *new users* (who displayed an interest and have been deemed eligible) enhances the credibility of the pipeline comparison design. With regard to the difference-in-difference analyses, the focus is on comparing *never users* and *new users*. Since we have panel data and can control for time-invariant observed and unobserved traits which may be associated with programme entry (obtaining a digester) there is no reason to expect that non-compliance compromises the analysis.[15]

[13] The distribution of the applicants, non-applicants and existing users among the 9 CPOs at baseline is provided in Table A.3.

[14] A probit model for dropping out does not reveal any systematic differences in the characteristics of those remaining in the sample and those who dropped out. The overall regression is statistically insignificant (p-value of 0.83).

[15] Nevertheless, we do assess whether there are systematic differences between compliers and non-compliers. First, (Table A.4) we compare observed household characteristics at baseline of compliers and non-compliers among the new users (initial applicants versus initial controls that obtained a digester) and never users (rejected applicants versus initial controls that did not obtain a digester). Second, we compare outcome variables at baseline values (Table A.5). Third, for both groups we estimate a logit that models the probability of not complying with initial assignment as a function of household characteristics at baseline (Table A.6). We find very little evidence of systematic non-compliance. There are some statistically significant differences in education level and living conditions, but most of these correlations disappear in the logit models. We find very little difference in the outcome variables, with about 5% of the tests showing a statistically significant result, which is along the lines of what we may expect of Type I errors in testing null hypotheses.

Table 5
Main characteristics of treatment and control groups (standard errors in parentheses).

Variable	Total	Always users	New users	Never users
Household size	4.07	4.15	4.15	4.00
	(1.22)	(1.18)	(1.21)	(1.24)
Number of children in the household	0.37	0.36	0.34	0.40
	(0.56)	(0.62)	(0.54)	(0.55)
Male head of household (%)	0.97	0.99	0.97	0.96
	(0.18)	(0.10)	(0.18)	(0.19)
Age of the head of household	46.14	45.41	46.24	46.27
	(11.31)	(8.79)	(10.82)	(12.18)
Dairy farming-main activity, head of household (%)	0.88	0.86	0.88	0.88
	(0.32)	(0.35)	(0.32)	(0.32)
Highest level of education in household (%)				
No more than primary school	0.35	0.26	0.37	0.37
	(0.48)	(0.44)	(0.48)	(0.48)
Junior high school	0.35	0.34	0.38	0.35
	(0.48)	(0.48)	(0.49)	(0.48)
Senior high school	0.23	0.31	0.20	0.22
	(0.42)	(0.46)	(0.40)	(0.42)
Vocational training	0.02	0.01	0.03	0.02
	(0.15)	(0.10)	(0.18)	(0.14)
Higher education	0.04	0.08	0.03	0.04
	(0.20)	(0.28)	(0.16)	(0.20)
Living conditions (%)				
Walls: cement or clay bricks	0.87	0.94	0.90	0.84
	(0.33)	(0.24)	(0.30)	(0.37)
Floor: concrete, stone or ceramic	0.89	0.96	0.90	0.86
	(0.31)	(0.20)	(0.30)	(0.34)
Roof: concrete or tiled	0.81	0.85	0.78	0.82
	(0.39)	(0.36)	(0.42)	(0.39)
Windows fitted with glass	0.69	0.72	0.73	0.66
	(0.46)	(0.45)	(0.45)	(0.47)
Number of rooms	6.17	6.72	6.10	6.06
	(1.61)	(1.75)	(1.49)	(1.61)
Electricity available in the house (%)	0.93	0.99	0.96	0.90
	(0.25)	(0.10)	(0.19)	(0.31)
Size of cultivated land (ha)	0.60	0.76	0.66	0.53
	(0.91)	(1.06)	(1.08)	(0.74)
Number of cows and buffaloes owned	5.22	6.88	5.69	4.49
	(3.68)	(4.83)	(4.54)	(2.34)
Household owns the farming land	0.23	0.26	0.29	0.20
	(0.42)	(0.44)	(0.45)	(0.40)
Number of households	677	97	216	364

Source: Indonesian biogas survey, 2011.

4.2. Sample characteristics

When we compare the 2011 baseline data with the nationally representative Indonesian socioeconomic household survey of 2011, we find that average annual per capita spending by the sampled dairy farm households is similar to average spending by Indonesian households in East Java who are engaged in the livestock sector. On average, the

Table 6
Number of digesters conditional on cow ownership and digester size (BIRU recommended number of cows in parenthesis).

	<2 cows	2 cows	3 cows	4 cows	5 cows	>6 cows
Always users						
4 m^3 (3 cows)	0	4	0	2	0	0
6 m^3 (4/5 cows)	3	2	8	8	12	19
8 m^3 (6 cows)	0	1	4	6	3	18
10 m^3 (7/8 cows)	0	0	0	0	1	3
12 m^3 (9 cows)	0	0	0	0	0	3
New users						
4 m^3 (3 cows)	0	0	0	0	0	0
6 m^3 (4/5 cows)	4	15	20	22	15	27
8 m^3 (6 cows)	1	6	14	15	17	33
10 m^3 (7/8 cows)	0	3	3	4	4	7
12 m^3 (9 cows)	0	0	1	0	0	5

Source: Indonesian biogas survey, 2012.

Table 7
Probability of purchasing fuel in the month preceding the survey.

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
LPG	2011	0.124	0.676	0.665	−0.605**	−0.608**	−0.548**	−0.552**
	2012	0.206	0.106	0.701	(0.000)	(0.000)	(0.000)	(0.000)
Kerosene	2011	0.041	0.042	0.077	0.020	0.021	0.024	−0.0004
	2012	0.000	0.009	0.025	(0.410)	(0.402)	(0.387)	(0.986)
Fire wood	2011	0.093	0.185	0.104	−0.115**	−0.094*	−0.135*	−0.092*
	2012	0.041	0.065	0.099	(0.002)	(0.024)	(0.014)	(0.037)
Batteries	2011	0.113	0.051	0.044	0.018	0.026	0.065	0.062*
	2012	0.041	0.042	0.016	(0.422)	(0.328)	(0.110)	(0.045)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%. *p*-values in parentheses.

dairy farmers in the sample sit between decile 4 and decile 5 of the national per capita expenditure distribution (Table A.7).

Profiles of the interviewed households are provided in Table 5. The average household size is about 4 members. The majority of the households are headed by a male (97%) with an average age of about 46 years. Dairy farming is the main professional activity (88% of the household heads). For a third of the sample, primary school is the highest level of education completed by any household member, while for another third of the sample, the highest level of education is junior secondary. Access to electricity is relatively high, with almost 90% of the households reporting access. The average size of a farm is 0.6 acres, just under a quarter of the households own the land they cultivate, and on average they own about 5 cows. About 92% of the interviewed households have 2 or more cows, which represents the minimum requirement for joining most of the cooperatives in the surveyed area, and is also the recommended minimum for operating a digester.

There are some differences between the two treatment groups (*new users* and *always users*) and the households without a digester (*never users*) which we need to take into account in the impact evaluation. Farms with a biogas digester, and especially the early adopters, have on average larger farms, more cows and are more likely to own their farm land. They also have higher levels of education than new and never users, while the latter two groups have comparable education levels. On average, houses owned by always users have more rooms and are of better quality (in terms of materials used for the walls, floor, roof and windows).

To examine whether the three groups are similar in terms of the probability of owning a digester we estimate logit models of digester ownership as a function of various socio-demographic characteristics. Few variables are statistically significant and the models have limited explanatory power and especially in the case of the pipeline comparison design sample the model (overall *p*-value 0.14) is not able to discriminate very clearly between the always users and the new users. In other words the two groups appear to be similar in terms of the probability of owning a digester (see Table A.8).

While differences in the probability of owning a digester may be limited the descriptive statistics do show that wealthier and better educated farmers are more likely to adopt biogas digesters. In the empirical analysis we rely on propensity score matching to ensure that the three groups are observationally equivalent in terms of the traits that determine ownership of a digester.

5. Financing, functioning and impact of digesters

As a prelude to examining the impact of biogas digesters, this section provides details on the financing and functioning of digesters. Thereafter, we discuss the econometric estimates.

5.1. Financing and functioning

The process to obtain a digester seems to run efficiently, as in 90% of the cases the time between submitting an application form and having a fully-constructed and functioning digester is 4 months or less. The bulk of the digesters (93%) are financed entirely through loans/credit offered at zero interest and payable over two to three years. The main source of credit as far as households are concerned is the cooperative to which they belong. This is a little misleading as almost all the cooperatives that are included in the survey sell their milk to Nestlé which in turn provides loans to cooperatives at 0% interest rate in order to enable digester purchases. The terms of re-payment differ across cooperatives but the amounts are deducted periodically (usually every 10 to 12 days) and automatically from the money owed by the cooperative to the individual member for milk sales. While most farmers (75%) were unable to provide information on the outstanding loans, they did have records on the total proceeds from milk sales, the deduction for repayment of the digester loan and the outstanding loan balance. None of the respondents expressed concerns about the repayment burden.

About half the households in our sample have a 6m^3 digester followed by 38% who have a 10 m^3 plant. Almost all the households (96%) reported that their digester was functioning as expected and enough gas was being produced. Prior to purchase, the three main reasons stated by respondents for buying a digester were reduced need for firewood (44%), faster cooking (33%) and a smokeless kitchen (26%). Other reasons were improvements in barn hygiene, less time needed to procure energy and use of bio slurry. Ex post, >90% mentioned that they had experienced these benefits.[16] In terms of overall levels of satisfaction, 47% of the respondents reported that they were "very satisfied" with their digester while 52% reported that they were "rather satisfied" and only 1% of the treated households stated that they were "rather unsatisfied". Consistent with the satisfactory remarks on gas production, there were limited complaints on the need for fixing or replacing digester parts. About 6% of digester owners reported that they have had to repair or replace parts since their digesters first became operational while about 3% had experienced unexpected effects such as a bad smell due to gas leaks, a non-working stove or problems with the thermometer.

In addition to construction of the digester, the availability of water and cow dung is crucial for the proper functioning of digesters and ensuring adequate gas flow. Table 6 compares the actual distribution of digesters by capacity and cow ownership to the recommended cow holding per digester size (in parentheses). About 44% of digester owning households do not have the recommended cow to digester size ratio, indicating that gas production could be hampered by insufficient fuel. This is most prominent among the new users, where about half the farms have less than the recommended number of cows as compared to a third of the always users. In terms of water availability, only 8% of the treated households stated that they faced water shortages. Notwithstanding the gap between recommended and actual ratios it does not seem that this aspect has a negative effect on household perceptions of gas production.

[16] While it is possible that the use of biogas versus wood leads to faster cooking, LPG does have higher energy content than biogas and less LPG is required to produce the same amount of heat. However, neither the survey data nor the qualitative work indicated that there were concerns about the heat produced by biogas.

Table 8
Gathering fire wood.

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
Gathered wood last Week	2011	0.258	0.662	0.706	−0.269**	−0.279**	−0.400**	−0.404**
	2012	0.247	0.394	0.706	(0.000)	(0.000)	(0.000)	(0.000)
Hours per week	2011	1.216	4.613	4.503	−3.816**	−3.945**	−2.989**	−3.397**
	2012	0.895	1.837	5.542	(0.000)	(0.000)	(0.000)	(0.000)
Bundles per month	2011	3.031	12.120	12.420	−7.70	−8.164**	−11.333**	−9.089**
	2012	2.546	4.644	12.643	(0.000)	(0.000)	(0.000)	(0.000)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%. p-values in parentheses.

Table 9
Fuel consumption in the month preceding the survey.

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
LPG (kg)	2011	0.495	6.236	4.907	−6.188**	−6.139**	−6.741**	−5.741**
	2012	1.144	0.667	5.525	(0.000)	(0.000)	(0.000)	(0.000)
Kerosene	2011	0.041	0.060	0.179	0.092	0.096	0.024	−0.019
(litres)	2012	0.000	0.009	0.036	(0.163)	(0.172)	(0.387)	(0.618)
Fire wood	2011	0.392	1.380	0.536	−0.718	−0.620	−0.900	−0.988
(bundles)	2012	0.082	0.648	0.522	(0.149)	(0.337)	(0.323)	(0.172)
Batteries	2011	0.216	0.097	0.093	0.049	0.077	0.096	0.119+
	2012	0.062	0.083	0.030	(0.328)	(0.213)	(0.285)	(0.075)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%. p-values in parentheses.

5.2. Impact of digesters

We present difference-in-difference estimates and pipeline comparison estimates without matching and also combined with propensity score matching. Propensity score functions are estimated separately for the difference-in-difference analysis, prob($D_{2012}=1|X_{2011}, D_{2011}=0$), and the pipeline comparison, prob($D_{2011}=1|X_{2011}, D_{2012}=1$). With minor exceptions, the explanatory variables included in the propensity score function are those presented in Table 8, all at their 2011 values.[17] The propensity score estimates and diagnostics show that the 5-nearest neighbor matching procedure balances the samples on all characteristics (see Table A.9, Figs. A.1 and A.2).[18]

5.2.1. Fuel use and expenditure

The digesters have a large effect on the probability of purchasing LPG and firewood, mainly because these are the two main fuels used for cooking and for which biogas is a substitute (Table 7). Across the four sets of estimates, we find that biogas users are at least 55 percentage points less likely to purchase LPG, which constitutes about an 80% reduction as compared to the baseline. The reduction in the probability of purchasing firewood is not as large as the effect on LPG, but the 9 to 14% reduction still cuts the share of households that purchase firewood by about 51 to 73% of baseline levels.

With regard to firewood, while households do purchase firewood they also tend to forage firewood from public forests. As shown in Table 8, in addition to a reduction in the probability of purchasing firewood, access to digesters reduces the probability of gathering wood by at least 27 percentage points or a reduction in the share of households that collect firewood by about 40%. Nevertheless, gathering firewood still remains common practice even for households with biogas. In 2012, about 39% of new users and 25% of always users reported that they gathered wood in the week prior to being surveyed. The effects on time spent gathering wood and the amount of wood collected are large, suggesting that also for persistent wood users there are time savings. On average, for new users, the time spent foraging drops by about 4 h per week (a reduction of about 85%) and they collect 8 fewer bundles of wood per month (67% reduction).[19]

In terms of quantity of fuel consumed, access to digesters leads to a reduction in the monthly use of LPG by 6 to 7 kg (Table 9). Essentially new users almost completely stop using LPG. We also see a reduction in the number of bundles of fire wood used but this effect is not statistically significant. This is perhaps not surprising as households tend to gather firewood from publicly accessible sources as opposed to purchasing firewood. The reduction in the purchase of LPG and firewood is also reflected in terms of energy spending (Table 10). Digester owners experience a reduction in monthly spending on LPG of between IDR 29,000 to IDR 37,000 per month and a reduction in expenditure on firewood of about IDR 19,000 to IDR 24,000, although the effect on firewood spending is not statistically significant for the matching estimates. The effects on LPG are especially striking as biogas appears to fully meet the demand for domestic gas, crowding out LPG. Overall, digester owning household experience a reduction in energy expenditure of between IDR 47,000 to IDR 65,000 a month.[20] Based on the more conservative DID-PSM estimate this translates into a 45% reduction in energy expenditures for new users as compared to their expenditures in

[17] Male head of household is dropped from both models and access to electricity from the pipeline-comparison propensity score function, due to lack of variation.

[18] The DID estimates are based on 97 always-users, 216 new-users and 364 never-users. The PSM-DID estimates are based on 201 new-users and 360 never-users, that is, 15 new-users and 4 never-users who could not be matched were removed from the analysis. The pipeline estimates are based on 92 always-users and 211 new-users, that is, 5 always-users and 5 new-users could not be matched.

[19] The unit of measurement for wood is "bundles of wood". There is no fixed weight of these bundles. Based on our field experience the weight of these bundles ranges from 6 to 9.5 kg.

[20] We also estimated the effect of having a digester on a range of other expenditure items such as food, various non-food items and total consumption expenditure. There were no clear patterns and for the most part the estimates were not statistically significant. Thus, while we do find a clear reduction in energy costs this does not translate into statistically significant changes in expenditure on other items.

Table 10
Fuel expenditure in the month preceding the survey (Indonesian Rupiah).

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
LPG	2011	2281	32,955	26,479	−29,076**	−30,012**	−36,987**	−30,674**
	2012	5391	3199	25,799	(0.000)	(0.000)	(0.000)	(0.000)
Kerosene	2011	371	531	1630	838	815	204	−159
	2012	0	102	364	(0.185)	(0.224)	(0.413)	(0.637)
Fire wood	2011	4660	29,125	5723	−19,202**	−20,584	−18,820	−24,465
	2012	902	8991	4790	(0.0097)	(0.196)	(0.470)	(0.231)
Batteries	2011	380	215	195	39	81	92	165
	2012	268	174	114	(0.769)	(0.618)	(0.625)	(0.248)
Electricity	2011	44,758	43,358	37,956	−145	−1199	−7907+	1399
	2012	49,641	42,227	36,970	(0.961)	(0.561)	(0.095)	(0.692)
Total expenditure	2011	54,935	109,587	75,243	−47,478**	−50,386**	−64,892*	−54,652*
	2012	58,616	57,672	70,806	(0.000)	(0.002)	(0.016)	(0.010)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%; p-values in parentheses.

Table 11
Number of cooking devices owned by households.

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
Wood fuel stove	2011	1.082	1.745	1.690	−0.395**	−0.349**	−0.628**	−0.663**
	2012	1.196	1.343	1.681	(0.000)	(0.002)	(0.000)	(0.000)
Kerosene stove	2011	0.062	0.037	0.060	0.035	0.052	0.039	0.025
	2012	0.093	0.097	0.085	(0.320)	(0.167)	(0.327)	(0.390)
Biogas stove	2011	1.856	0.000	0.000	1.552**	1.536**	1.870**	1.856**
	2012	1.619	1.560	0.008	(0.000)	(0.000)	(0.000)	(0.000)
LPG stove	2011	0.536	1.088	1.159	−0.532**	−0.554**	−0.652**	−0.552**
	2012	0.732	0.583	1.187	(0.000)	(0.000)	(0.000)	(0.000)
Rice cooker	2011	0.103	0.097	0.091	−0.030	0.021	−0.057	0.006
	2012	0.134	0.037	0.060	(0.358)	(0.553)	(0.220)	(0.873)
Magic com	2011	0.495	0.421	0.440	0.006	−0.004	0.089	0.074
	2012	0.660	0.551	0.563	(0.923)	(0.994)	(0.262)	(0.244)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Magic coms run on electricity and are used for cooking and warming rice. Significance levels: + 10%, * 5%, ** 1%; *p*-values in parentheses.

2011 (with the pipeline comparison effect at 59%), and a reduction in total household expenditure of about 3.5%.[21]

So far the discussion has focused on the replacement of LPG and firewood by biogas. However, does the availability of a digester also translate into greater energy usage? Based on their analysis of the kerosene to LPG conversion programme, PT Pertamina and WLPGA (2012) find that, on average, a household that relies only on LPG for cooking uses about 9 kg of LPG a month. According to BIRU the smallest digester (4 m^3) produces 1 m^3 of biogas per day. The replacement value of 1 m^3 of biogas is 0.43 kg of LPG implying that the smallest digester is able to produce the energy equivalent of about 13 kg of LPG per month. Whether this translates into additional energy usage is unclear, however, households with access to digesters certainly seem to have the potential to increase their energy usage.[22]

[21] It is unlikely that the results on fuel use and expenditure are influenced by the kerosene to LPG conversion program as by 2009, East Java, including all the districts surveyed in the paper had been covered by the conversion scheme (PT Pertamina and WLPGA, 2012). Indeed, as shown in Table 1 of the paper, in 2011, only 1.3% of those in sampled districts still relied on kerosene for cooking. Hence, it is very unlikely that during the period 2011-2012 the different categories of biogas users/non-users could have been exposed to a different policy environment and that the conversion programme could have played a role in influencing the estimates.

[22] Based on information from 62 village-level interviews which were conducted at the same time as the follow-up survey in 2012, there is some evidence that the availability of additional energy is being used to expand economic activities. In 65% of the interviews the village-heads mentioned that the availability of biogas had led to the creation and expansion of food-related businesses for women. These comments were echoed by cooperative representatives whom we interviewed in April 2012. During the interviews the respondents mentioned that 6 women in their locality had opened small bakeries mainly due to the availability of cheap/free biogas.

5.2.2. Cooking patterns and air quality

The use of bio-digesters is expected to translate into improved air conditions, especially in kitchens, due to enhanced use of biogas stoves and reduced use of wood stoves which are associated with emission of biomass particulates. As may be expected, biogas fuelled cooking stoves are universal among households with a digester. However, most households still maintain a wood fuel stove. Among the control group almost all households own a wood fuel stove and the large majority also have a LPG stove. Consistent with the impact estimates for energy use, we find that the use of digesters is associated with a displacement of LPG and wood fuelled stoves (see Table 11). The average number of wood fuel stoves owned by new users falls by about 20% and the ownership of LPG stoves declines by about 50%.

For both the new and the always users, biogas stoves are the most prominent cooking device used (see Table 12). In 2012, 92% of always users and 84% of new users reported that they had used their biogas stove in the week preceding the survey. The predominant use of biogas stoves as opposed to the intensive use of the wood fuel and LPG stove by the control group indicates a clear pattern of substitution driven by access to biogas. Although more than half the households with a digester still own a LPG stove, these stoves are all but redundant. Firewood stoves remain in use for about one tenth of treated households, which implies a 70% reduction due to biogas.

Consistent with the reduction in the use of wood fuelled stoves, there are sharp differences in the self-assessed quality of air in kitchens across treatment and control groups. Based on the DID estimates the likelihood of reporting that air quality is good is 19 to 25 percentage points higher for the treated as compared to the controls. For the treated group the source of the poor air quality is far less likely (at least 16 percentage points) to be due to the burning of wood (Table 13). We also

Table 12
Cooking devices used by households in last week.

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
Wood fuel stove	2011	0.072	0.634	0.657	−0.471**	−0.479**	−0.553**	−0.562**
	2012	0.082	0.125	0.618	(0.000)	(0.000)	(0.000)	(0.000)
Kerosene stove	2011	0.000	0.000	0.003	0.005	0.006	0.000	0.000
	2012	0.000	0.005	0.003	(0.454)	(0.432)	(n.a.)	(n.a.)
Biogas stove	2011	0.856	0.000	0.000	0.826**	0.830**	0.859**	0.856**
	2012	0.918	0.843	0.016	(0.000)	(0.000)	(0.000)	(0.000)
LPG stove	2011	0.041	0.310	0.305	−0.343**	−0.335**	−0.317**	−0.269**
	2012	0.000	0.014	0.352	(0.000)	(0.000)	(0.000)	(0.000)
Rice cooker	2011	0.000	0.005	0.000	−0.005	−0.005	−0.002	−0.005
	2012	0.000	0.000	0.000	(0.194)	(0.317)	(0.806)	(0.503)
Magic com	2011	0.031	0.046	0.036	−0.005	−0.012	−0.002	−0.015
	2012	0.000	0.014	0.008	(0.794)	(0.592)	(0.939)	(0.530)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%; p-values in parentheses.

Table 13
Air quality in kitchens (%).

	Year	Always users (T1)	New users (T2)	Never users (C)	DID (T2-C)	DID-PSM (T2-C)	Pipeline-PSM (T1-T2)	Pipeline difference (T1-T2)
Air quality good	2011	0.979	0.727	0.780	0.235**	0.237**	0.191**	0.253**
	2012	0.887	0.745	0.563	(0.000)	(0.000)	(0.000)	(0.000)
Bad air from	2011	0.010	0.222	0.176	−0.313**	−0.290**	−0.165**	−0.212**
wood fire	2012	0.041	0.074	0.341	(0.000)	(0.000)	(0.001)	(0.000)
Bad air from	2011	0.000	0.000	0.000	0.009	0.036	0.000	0.000
kerosene	2012	0.031	0.097	0.088	(0.707)	(0.205)	(n.a.)	(n.a.)

Source: Indonesian biogas survey, 2011 and 2012. *Notes:* Significance levels: + 10%, * 5%, ** 1%; p-values in parentheses.

analysed the effect (not reported) of owning a digester on a variety of health outcomes such as respiratory diseases, eye-related conditions - itching, redness, tears, and headaches. We found no evidence that access to digesters is associated with positive health effects. Overall, while there is a clear improvement in the quality of air in the kitchen this has not yet translated into clear-cut health effects.[23]

5.2.3. Benefits and payback period

As discussed in Section 2, while the BIRU program has met its target of installing 8000 bio-digesters over a four-year period, the geographical distribution of these digesters is quite different from the envisaged distribution. The bulk of the digesters (62%) are located in East Java and as will be discussed below, this may be attributed mainly to the favourable basis on which farmers in East Java can access credit.

The cost of purchasing the most popular digester (6 m^3) is 6.3 million IDR which is about 1.4 times the annual per capita expenditure of a dairy farming household in East Java.[24] If the subsidy is taken into account the cost falls to about 4.3 million IDR or 0.93 times the annual per capita expenditure of a dairy farming household. Given the size of the investment as compared to their annual per capita expenditure, dairy farmers need to borrow in order to finance the digester purchase. In East Java, farmers are able to finance their purchases through loans obtained through their cooperatives. These loans are provided by Nestlé to cooperatives at zero interest which are in turn passed on to farmers interested in purchasing a digester.[25] Over a two to three year period, loan repayments are deducted from the payments farmers receive for delivering their milk to the cooperative. As compared to East Java, dairy farmers in other provinces do not have access to loans at zero financing costs.

To examine whether it is worthwhile for farmers to invest in a digester we use information on the costs of purchasing a digester and our estimate of the main financial benefit currently being generated by digesters (see Table 14) to provide a payback analysis for a 6 m^3 digester.[26] We provide payback estimates with and without taking into account financing costs and also with and without accounting for the subsidy. As shown in Table 14 (estimates with discounted benefits) the estimated payback period, if a dairy farmer has to bear the full cost of a digester and also finance the purchase, is 30 years. Given the expected 20-year lifetime of a digester and the benefits currently being generated through the digester, it is clearly not a sensible investment.[27] As is the situation in other provinces, excluding East Java, if farmers have to finance the purchase but are able to avail the subsidy then the payback period falls to 14 years while the combination of a subsidy and zero financing costs, as in East Java, reduces the

[23] While biogas is primarily used for cooking, a small proportion of households (11% of always users and 4% of new users) also use it for lighting. The limited use of biogas for lighting is expected as most households in the sample have access to grid electricity and the quality of illumination provided by biogas lamps is poor. Our field visits confirmed the limited use of biogas for lighting and given the low uptake of biogas lamps there is little impact on the availability or use of conventional sources of lighting. We also examined whether access to digesters/bio-slurry is systematically related to expenditure on fertiliser. While the point estimates suggest that access to a digester is associated with a reduction of at most IDR 3500 a month on chemical fertilisers, the effect is not statistically significant. We find a large and positive coefficient (IDR 1,686,366) for the effect of digester ownership on annual revenues from agricultural output, but these estimates are also not statistically significant. The reduction in expenditure on fertiliser and the increase in crop revenues, albeit not precise, suggests that that there is substantial variation across treated households in the extent to which they substitute bio-slurry for fertilisers and the manner in which they apply bio-slurry to their land.

[24] Dairy farming household are in decile 4 and decile 5 of the national per capita expenditure distribution (see Table A.7).

[25] Nestlé provides these loans as part of its "Creating Shared Value" initiative. The company purchases fresh milk from about 33,000 dairy farmers belonging to 31 cooperatives in East Java for a factory which produces milk, food, and beverage products.

[26] We only consider reduced energy expenditure as we did not find statistically significant effects on health outcomes or on other outcomes such as expenditure on fertiliser and agricultural revenues. Nevertheless, we did compute payback periods which took into account the effect of owning a digester on (a) annual reduction in expenditure on fertiliser (IDR 42,000) and (b) annual increase in agricultural revenues (IDR 1,686,366). As may be expected, accounting for (a) does not lead to a substantial change in the payback periods presented in Table 14, however, including the effect on agricultural revenues leads to a payback period of between 2 and 4 years.

[27] BIRU digesters have an expected lifetime of 15-20 years although during field interviews it was pointed out that digesters may last for about 30 years.

Table 14
Payback analysis for a 6 cubic metre digester.

Payback analysis (Without discounting future benefits)		Excluding financing costs	Including financing costs
Cost of current digester without subsidy (IDR)	6,300,000		
Cost of current digester with subsidy (IDR)	4,300,000		
Financing costs for digester without subsidy [a] (IDR)	1,512,000		
Financing costs for digester with subsidy[a] (IDR)	1,032,000		
Annual repairs and maintenance costs[b] (IDR)	5755		
Annual water costs [c]	0		
Benefit - annual reduction in energy expenditure [d] (IDR)		569,736	
Payback period current digester without subsidy		11 years	14 years
Payback period current digester with subsidy		8 years	9 years
Payback analysis (discounting future benefits)[e]			
Payback period current digester without subsidy		19 years	30 years
Payback period current digester with subsidy		10 years	14 years

Notes: The analysis is based on a 6 m3 digester as 50% of households have a digester of this size.
[a] Based on the sample data, 93% of the digesters are financed through loans offered at zero interest by the cooperative to which the dairy farmer belongs. Since this arrangement of zero financing costs is specific to East Java (Nestlé) we estimate financing costs based on the terms provided by Bank Syariah Mandiri (BSM) - interest rate of 8% payable over 3 years.
[b] Based on the sample data, on average, households have spent IDR 5755 per year on repairs. Since the average age of a digester in our sample is 13 months, this figure is likely to underestimate annual maintenance costs.
[c] Water from traditional sources (rain water/rivers/springs) is free and our sample data show that household do not face any difficulties acquiring water from public sources to feed their digesters.
[d] We do not impute monetary benefits for reduced time spent gathering firewood. 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 realized at the moment.
[e] Future benefits are discounted at an opportunity cost of capital set at 6%. It is assumed that households are able to earn this rate on a long-term savings account. In April 2013, Bank Negara Indonesia offered an interest rate of 6% on term deposits. The formula used for calculating the discounted payback period without subsidy is Ln(1/(1-(cost of investment*discount rate)/savings))/Ln(1 + discount rate).

payback period to a relatively attractive 10 year timespan. From the perspective of an individual farmer, given the current level of benefits generated through digesters, one of the two – either a subsidy or no-cost financing is essential in order to justify the investment. The payback analysis highlights that one of the main reasons for the focus of the programme on East Java has been the supply of credit from Nestlé. It is hard to conclude that without the subsidy *and* without access to credit on such favourable terms the programme would have been able to reach its expected targets.[28] Clearly, if the programme is to prosper without any public subsidies and farmers are expected to acquire credit at market rates then additional private benefits such as increased agricultural revenues due to application of bio-slurry and savings on fertiliser expenditure need to be realized. Of course it may be argued that a payback analysis which focuses only on a limited set of private benefits is incomplete and given the potential reduction in the negative environmental consequences of indiscriminate dumping of cow dung, subsidies are justified.[29]

6. Concluding remarks and policy implications

This paper provided an assessment of Indonesia's Domestic Biogas Program (BIRU) on fuel use and energy expenditure. The paper adds to the limited body of research which has systematically examined the effects of such initiatives. It was based on two rounds of farm household panel data and qualitative data collection in 2011 and 2012. The analysis focused on the province of East Java, which at the end of 2012 accounted for about 62% of all BIRU digesters. To identify causal effects of the program we exploited changes in digester ownership over time to apply a difference-in-difference analysis, by comparing new digester users with a control group that did not own a digester. In addition, the phased roll out of the program offered an opportunity to conduct a pipeline comparison approach, where households that were about to obtain a digester were compared with existing users. Methodologically, the paper places the literature on the impacts of biogas on a stronger empirical footing, however, it should be emphasized that the estimates are specific to East Java.

Regardless of the empirical approach, the estimates showed that the biogas supply from the BIRU digesters has almost completely replaced the use of liquefied petroleum gas and greatly reduced the use of firewood for cooking. The availability of biogas has reduced average household energy expenditure by about 45%, or about 3.5% of total household expenditure. In addition, time spent collecting firewood falls by about 85%. The results also displayed a negative relationship between owning a biogas digester and expenditure on fertiliser, as well as a positive association with farm revenues, however, these effects were not statistically significant. This suggests that for the economic benefits of a by-product such as bio-slurry to materialize, its application needs to be sufficiently expanded and customized to local conditions.

The effects of biogas on fuel use and energy expenditure are large and the program has met its target of setting up 8000 digesters over a 4-year period. However, there is a large gap between the expected geographical distribution of the digesters and the actual distribution with the bulk of the program's activities focusing on East Java. This is not a coincidence as East Java offers a number of favourable conditions, such as a high concentration of cows, organization of farmers in cooperatives and financial support in the form of interest-free loans from Nestlé which has business interests in the region.

A payback analysis for investing in a digester revealed that in East Java, based on the financial benefits detected in the paper, and the current level of subsidy provided by BIRU and Nestlé, investing in a digester yields a payback in a relatively attractive period of 10 years. Thus, at least in East Java, as long as the current structure of the program is maintained there is ample scope for expansion as of the about 33,000 dairy farmers in the region only 4500 have digesters. Moving away from East Java or more importantly moving to a situation without the two subsidies and given the current level of benefits, investing in a digester has a payback period of 30 years which may be contrasted with the expected 20-year life time of a digester. While there are arguments to be made for continued public support of such clean energy initiatives,

[28] In two of the three cooperatives that were visited, respondents argued that at the moment the subsidy from BIRU was more important than technical support.
[29] In addition to their work as dairy farmers, the majority (93.5%) of the respondents also cultivate land. While a part of the cow dung generated is used as a fertiliser or for fueling their digesters, about 22.5% admitted that they still dumped cow dung into open drains, lakes/rivers. This proportion (31.3%) is higher among those who don't own digesters as compared to new users (15.6%) and always users (7.2%).

clearly from a private perspective given the current level of financial benefits, an unsubsidized program is not viable.

Indeed, if biogas is to be more than a niche source of energy in Indonesia and elsewhere and prosper without subsidies, then a reduction in energy costs associated with a digester investment is not enough and additional financial benefits need to be realized. Most obviously and a strategy being pushed by BIRU is more effective use of bio-slurry by digester owners and the development of a market for bio-slurry. This requires research and public policy support on the best way of applying and transporting bio-slurry, identifying crops that are most receptive to its application, and developing additional uses of bio-slurry so that it may replace fertilisers and pesticides while at the same time enhancing agricultural revenues.[30] Additionally, while fixed-dome concrete digesters of the type used by BIRU and in other countries are considered to be of high-quality, lowering the cost of a digester while at the same time maintaining its quality requires research on alternative designs. For instance, in Rwanda, researchers are working on the design of cheaper digester models which use less concrete and rely on burnt bricks.[31] To conclude, while biogas is a cheaper, cleaner fuel as compared to traditional alternatives and has the potential to replace both firewood and LPG, the continued spread of biogas hinges on reducing the payback period associated with the investment.

Acknowledgements

We thank staff from Indonesia's Household Biogas Program (BIRU) for their co-operation and two anonymous referees, Gunther Bensch, Rebecca Niemann and Jörg Peters for their comments. The data used in this paper was collected as part of an evaluation commissioned by the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. IOB support is gratefully acknowledged.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2017.09.006.

[30] For instance, research by BIRU shows that the application of bio-slurry along with the installation of irrigation channels has a positive effect on the growth of root vegetables, mushrooms, paddy, sugarcane, fruit trees, and nursery saplings. Other recent applications include the use of bio-slurry as a pesticide either on its own or in combination with 15-20% pure pesticide. It has also been suggested that dried digested slurry has the potential to be used as a feed supplement for livestock. For additional details see, http://www.biru.or.id/en/index.php/bio-slurry/.

[31] Depending on digester size, the redesigned digester models are 14.6 (for the 4-m^3 model) to 24.8% cheaper (for the 10 m^3) as compared to existing models (see Bedi et al., 2015).

References

Asian Development Bank, 2015. Fossil fuel subsidies in Indonesia: trends, impacts, and reforms. Mandaluyong City, Philippines. Retrieved from. https://www.adb.org/sites/default/files/publication/175444/fossil-fuel-subsidies-indonesia.pdf.

Bedi, A.S., Pellegrini, L., Tasciotti, L., 2013. Impact Evaluation of Indonesia's Domestic Biogas Programme. Retrieved from http://eprints.soas.ac.uk/23459/1/impact-evaluation-of-netherlands-supported-programmes-in-the-area-of-energy-and-development-cooperation-in-indonesia.pdf.

Bedi, A.S., Pellegrini, L., Tasciotti, L., 2015. The effect of Rwanda's program on energy expenditure and fuel use. World Dev. 67 (3), 461–474.

Garfí, M., Ferrer-Martí, L., Velo, E., Ferrer, I., 2012. Evaluating benefits of low-cost household digesters for rural Andean communities. Renew. Sust. Energ. Rev. 16 (1), 575–581.

Groenendaal, W., Gehua, W., 2010. Microanalysis of the benefits of China's family-size bio-digesters. Energy 35 (11), 4457–4466.

Hessen, J., 2014. An Assessment of Small-Scale Biodigester Programmes in the Developing World: The SNV and Hivos Approach. Vrije University, Amsterdam (Retrieved from https://energypedia.info/images/8/82/Van_Hessen_-_An_Assessment_of_Small-Scale_Biodigester_Programmes_in_the_Developing_World_The_SNV_and_Hivos_Approach.pdf).

International Institute for Sustainable Development, 2011. A citizen's guide to energy subsidies in Indonesia. Geneva, Switzerland. Retrieved from. https://www.iisd.org/gsi/sites/default/files/indonesia_czguide_eng_update_2012.pdf.

Katuwal, H., Bohara, A.K., 2009. Biogas: a promising renewable technology and its impact on rural households in Nepal. Renew. Sust. Energ. Rev. 13 (9), 2668–2674.

Laramee, J., Davis, J., 2013. Economic and environmental impacts of domestic bio-digesters: Evidence from Arusha, Tanzania. Energy Sustain. Dev. 17 (3), 296–304.

Program Evaluation Organisation, 2002. Evaluation Study on National Project on Biogas Development. Planning Commission, Government of India, New Delhi (Retrieved from http://planningcommission.gov.in/reports/peoreport/peoevalu/peo_npbd.pdf).

PT Pertamina, WLPGA, 2012. Kerosene to LP gas conversion programme in Indonesia: a case study of domestic energy. Retrieved from. http://www.wlpga.org/publication/kerosene-to-lp-gas-conversion-programme-in-indonesia/.

Rakotojaona, L., 2013. Domestic Biogas Development in Developing Countries. ENEA Consulting, Paris (Retrieved from http://www.enea-consulting.com/wp-content/uploads/2015/05/Open-Ideas-Domestic-biogas-projects-in-developing-countries.pdf).

SNV, 2009. Feasibility of a National Programme on Domestic Biogas in Indonesia. SNV Netherlands Development Organization.