Public Disclosure Authorized

Public Disclosure Authorized

WPS6102

Policy Research Working Paper 6102

Greening China's Rural Energy

New Insights on the Potential of Smallholder Biogas

Luc Christiaensen
Rasmus Heltberg

The World Bank
Development Research Group
Poverty and Inequality Team
June 2012

Abstract

Clean, safe energy for rural areas is an important component of green growth and sustainable development. Biogas could be an important contributor, if its record in reality lives up to its expected potential. This paper provides a preliminary assessment of biogas use by smallholder farmers in rural China, using data collected from 2,700 households in five provinces. The authors find that user satisfaction is high, and environmental and economic benefits appear tangible. There are strong indications of reduced use of wood and crop residues for fuel. Less time is spent on collecting fuel wood and cooking, which is especially beneficial to women. Adopters also save on fertilizers, because of the use of biogas residues. Moreover, problems with suspension of biogas use, whether due to technical or human factors, remained limited. However, few tangible benefits to respiratory health were detected. Overall, these findings are grounds for optimism about the potential for of smallholder biogas to contribute to more sustainable development, in China and beyond.

This paper is a product of the Poverty and Inequality Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at lchristiaensen@worldbank.org.

The Policy Research Working Paper Series disseminates the findings of work in progress to encourage the exchange of ideas about development issues. An objective of the series is to get the findings out quickly, even if the presentations are less than fully polished. The papers carry the names of the authors and should be cited accordingly. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

Produced by the Research Support Team

Greening China's Rural Energy:

New Insights on the Potential of Smallholder Biogas

Luc Christiaensen and Rasmus Heltberg[1]

The World Bank

JEL Codes: Q42, Q56, I12

Key words: household energy, biogas, renewable energy, China, fuel switching, indoor air pollution

Sector Board: Luc Christiaensen (EPOL) and Rasmus Heltberg (SDV)

---

[1] Luc Christiaensen (lchristiaensen@worldbank.org) and Rasmus Heltberg (rheltberg@worldbank.org) are Senior Economists at the World Bank. They are indebted to Anqing Shi for excellent research assistance, Prof. Liu Qiming of the China Agricultural University for collaboration with data collection and survey design, and Wendao Cao and Sari Soderstrom, task managers of the World Bank supported Ecofarming project under which the data have been collected. The research benefited from financial support under the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) funded by the governments of Norway and Finland. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors or the governments they represent.

1 Introduction

Biogas has long been recognized as a technology with vast environmental, economic and health benefits. Biogas installations convert animal and human dung into a clean and environmentally friendly energy source for efficient cooking[2], thereby reducing emissions of methane, an especially potent greenhouse gas. By displacing the solid fuels commonly used for cooking in developing countries, such as wood, charcoal and coal, it further reduces the adverse effects of these fuels, including inefficient time use due to collection and longer cooking times, indoor air pollution (IAP), and local environmental pressures. Finally, biogas slurry can be used as fertilizer, and by capturing and containing animal waste, biogas systems substantially improve the sanitary environment.

Biogas, in other words, would appear to be the ideal technology for sustainable development. Moreover, as women bear the largest burdens of solid fuel use in terms of cooking time, fuel collection time, and exposure to IAP while cooking, it is particularly gender friendly (Kohlin et al, 2011). Why then has the uptake of biogas been nowhere commensurate with its potential (Parawira, 2009; Katuwal and Bohara, 2009)[3]? And, when adopted, why has it often been abandoned only a little later?[4] At the same time, mounting concerns over climate change and the opportunities for securing carbon financing are rekindling interest in biogas as an important renewable energy source that can reduce the overwhelming reliance on biomass fuels in rural areas[5], reduce greenhouse gas emissions, and exploit

---

[2] More recent developments in Europe, China and elsewhere are increasingly using crop waste (e.g. straw) as feedstock for biogas installations. This paper, however, will specifically use the term biogas in the context of small-scale installations—household or small farm—using animal waste.

[3] Chen et al (2010a) estimate that only 19% of China's biomass potential is utilized.

[4] Under the slogan "biogas for every household" China began mass adoption in 1975, constructing 1.6 million digesters annually within the first years. However, due to low quality, by 1980, half of them were no longer in use. Similarly, in India, too rapid an implementation policy in the early 1990s led to poor design and widespread abandonment. Massive suspension has also been the fate of biogas digesters in Sri Lanka, with only one-third of digesters functioning properly shortly after installment, and in Kenya, where only 25 percent of those initially installed were still functional a couple of years later (Ho, 2005).

[5] Globally, 2.7 billion people (39% of global population) lack access to clean cooking facilities, while in China, this is true for 423 million, or 32% of the population. In China, 89% of people without clean fuels are in rural areas (IEA, 2011).

the opportunities presented by the rapidly expanding livestock sector as incomes grow (World Bank, 2007).

This increasing worldwide interest in biogas as an alternative renewable energy source is perhaps best illustrated by China's renewed embrace of biogas (Hu, 2008; Zheng et al., 2010; Chen et al., 2010a; Chang et al., 2011). China's rapid growth is fueling rapid growth in energy demand across all sectors. While it is the rise in urban and manufacturing energy demand that has attracted the most attention, rural energy use is also on the rise, resulting in a rapid expansion in the use of coal and fuelwood, with their associated environmental challenges for air quality and forest conservation (Yisheng, Minying, and Zhen, Undated).

To manage this situation and build a "new socialist countryside" that is also freed of the environmental and health concerns posed by untreated animal waste, the Chinese government has been actively pursuing a range of renewable energy options over the past 5-7 years, including support for smallholder biogas expansion. According to sources cited by Chen et al. (2010a), biogas provided less than 1 percent of total rural energy in 2003, but government plans called for rapid scaling up, with 6 million new digesters to be installed annually. These efforts received an additional impetus in the adoption of the latest 12th Five Year Plan (2011-2015), which vigorously strives to green China's growth process and lower its carbon intensity, also in the rural sector.

Yet, despite the massive scale and speed at which China's biogas program is being rolled out, little is known about the actual benefits to users on the ground, whether the current approach to fostering adoption with a larger emphasis on improved technologies and support systems pays off,[6] and whether biogas adopters sustain its use. Reports of fairly widespread suspension of biogas by households after initial adoption are for example emerging once again (Chen et al., 2010b), just like in

[6] Current policy practice focuses for example on greater awareness, cold fermentation technology to increase the efficiency of biogas production in colder regions (Chen et al., 2010), improving ancillary services, and financial subsidies (Walekhwa, Mugisha, and Drake, 2009) to speed up adoption.

the past, and not unlike what has often been observed with alternative household energy technologies such as improved stoves. But, this time it may not be because of defunct technologies or support systems, but rather because of rising rural wages and urban migration (Zhang, Yang, and Wang, 2012). Better empirically grounded insights regarding the benefits from biogas use as well as the factors affecting the adoption *and* suspension of biogas utilization are needed. This will help gauge the potential of smallholder biogas for improving household welfare and health and greening growth, both in China and beyond.

To shed preliminary light on these issues, this paper analyzes a comprehensive survey of 2,700 households from 225 villages collected under a World Bank co-funded *Eco-farming project* aimed at providing household biogas systems to 400,000-500,000 rural smallholder households in 5 provinces of rural China. In its analytical approach, the study uses "thick" descriptive analysis based on multivariate analysis of cross-sectional data, consistent with most of the renewable energy literature so far. However, contrary to most of this literature, the sample used here is much larger and documents the experience from a large nationally implemented program, as opposed to a small NGO-run program. Also, using a purposively-designed sample and questionnaire, the paper analyzes the use of biogas in conjunction with the broader rural household energy mix, thereby enabling a more comprehensive and comparative analysis of rural household energy use, including the identification of fuel switching patterns and its correlates, as well as the identification of entry points for better targeting of biogas programs to increase adoption and reduce suspension.

In particular, the following issues are addressed:

- What are the current fuel use patterns in this part of rural China, and what is the role of biogas in promoting transition to clean fuels?
- Does the preliminary evidence support the purported benefits of biogas?

- Based on project experience, household statements, and multivariate analysis, what are the constraints to greater biogas uptake and sustained use?

The findings from the baseline survey suggest that biogas is delivering on its potential. User satisfaction is high; there is evidence of fuel switching, especially away from fuelwood and crop residues, and lower fuelwood collection time, benefiting women in particular; and farmers report they are able to save on fertilizers and insecticides by using biogas residues. The quality of equipment and support structures appears adequate: breakdowns are few and quickly fixed, and most suspension of biogas after initial uptake appears to be temporary and related to, for example, families migrating or having too few animals at some point during the year.

The paper proceeds by describing the sampling and data collection, followed by a broad description of fuel use patterns in the sampled households (section 2). Preliminary indications of the welfare impacts of biogas are presented in section 3, while section 4 identifies the key factors associated with biogas uptake, use, and suspension. Section 5 presents some concluding remarks.

2 Household Fuel Use Patterns in Rural China

Following the adoption of its 11th 5-year plan in 2006, the Government of China (GoC) rekindled its national biogas program, which the World Bank joined in 2009 through a 5-year US$440 million Eco-farming project, of which US$120 million to be provided by a World Bank loan. In addition to expanding biogas provision to an additional 400,000-500,000 rural smallholder households, the project seeks to test an enhanced project design which complements the subsidized provision of biogas digesters to smallholders with the simultaneous construction of an improved kitchen, by connecting the toilet to the digester, and providing technical assistance for productive use of the biogas slurry as fertilizer. This enhanced project runs alongside the national biogas project, which only provides subsidized biogas digesters. It operates in 64 counties of five south-eastern provinces, namely Anhui, Chongqing, Guangxi, Hunan and Hubei. These areas are characterized by small family sizes, widespread outmigration of working-age adults, and an aging remaining population. They also struggle with varying degrees of deforestation and other environmental problems (World Bank, 2008).

The operation of a smallholder biogas digester (which in China is usually a 10-12 m^3 cement container buried underground next to the pigsty) requires the dung from at least 3 pigs as feedstock for the anaerobic digestion that produces the gas, in addition to other animal and human dung. Smallholder biogas is thus best suited for farms with penned as opposed to grazing animals, whose dung can be channeled automatically into the digester. Having a sufficient number of animals and space near the house to construct the biogas digester is usually a prerequisite to qualify for a digester construction subsidy.

Many Chinese smallholders fulfill this requirement, as small-scale pig raising has long been a tradition in Chinese mixed farming systems, partly linked to the traditional pigroast for the Lunar New Year Festival celebrated in China each January or February. However, because of its costs (US$285 on average for this sample, see below) and the need for a minimum quantity of animals to supply sufficient feedstock, biogas is unsuitable for the poorest smallholders.[7] At the same time, looking forward, the pork sector is undergoing a rapid reorganization into large scale production entities (Christiaensen, 2012).[8] How this will affect the sustainability of current smallholder biogas systems is unclear.[9]

---

[7] Improved biomass stoves may be the better alternative to reduce IAP for the poorest, or higher subsidies for the poor with animals.

[8] In addition to expanding its smallholder biogas program, the government is also promoting the construction of large-scale biogas stations, especially in the developed east coast regions where many industrialized large livestock farms are based. Rabobank estimates that by 2015, nearly three-quarters of the pigs in China will be reared in commercial farms compared with 63 percent in 2010. In 2000, farms with more than 50 pigs constituted just 26 percent of the output (Reuters News, 2011).

[9] This evolution does not automatically have to translate in a suspension of current smallholder biogas use. The growth in pork demand may be met by the larger production entities, while current smallholder pig holding

To monitor and evaluate progress of the Eco-farming project, a baseline survey of 2,700 households was conducted during the second half of 2009. This is the first phase in a larger effort to more accurately evaluate the impact of the project.[10] In total, 225 villages were selected, spread equally across 3 counties in each of the 5 provinces in which the project is active. Counties were stratified by physical and economic characteristics.[11] Within each county, two townships were selected purposively, and within each township, two project and three non-project villages.[12] Non-project villages were slightly oversampled (135 non-project versus 90 project villages) to ensure a sufficient number of pure control villages that have neither the World Bank supported nor the national biogas program. In both project and control villages, the survey randomly sampled households meeting the criteria to qualify for biogas subsidies. To also permit within project village impact analysis in the future, households were slightly oversampled in project villages—fifteen households in the project villages versus 10 per non-project village. The survey instruments comprised a household questionnaire covering all aspects of fuel and energy consumption, experiences with biogas, and a range of socio-economic conditions as well as a village questionnaire covering infrastructure and socio-economic development.

The baseline data described above forms the information base for this paper. At the commencement of the Eco-farming project at the beginning of 2009, a number of households already owned a biogas digester. In particular, the sample contains 610 households (23%) with biogas installed, of which approximately 147 were provided as part of the Eco-farming project. The remainder received it with support from various government agencies or constructed it themselves. The study exploits this feature of the data to situate the current use of biogas within the overall energy mix in this part of rural

---

continues. The smallholder digesters may also be filled with manure from the larger farms, as has been reported on a couple of occasions during our field visits.

[10] Two follow up panel surveys are planned in the fall of 2011 and 2013 respectively.

[11] The selected counties are Houqiuxian, Ningguoxian, and Taihuxian in Anhui province; Jjianjinqiu, Wanzhouqiu, and yungyianxian in Chongqing; Xingan, Pinglo, and Fangcheng in Guangxi; Lensuitangqiu, Wugangshi, and Yongdingqiu in Hunan; and Enshixian, Janshi, and Xiuenxian in Hubei.

[12] Slightly fewer villages were selected in Guangxi Autonomous Region.

China and shed light on the welfare effects of biogas use, emerging adoption patterns, and durability of this new wave of biogas systems. While the results from this data are obviously not statistically representative for China or any of the provinces as such, they provide nonetheless a good basis for descriptive inferences about biogas in rural China.

Reviewing the availability of different fuels across the sample, all except two villages were electrified. Villagers also report that fuelwood is mostly quite easily available, although around one-fifth find it becoming hard to access, and fuelwood markets are emerging. LPG is used in around 65% of sample villages, and coal in 59%, reflecting a sample that straddles both the colder North and the hotter South China where there is less need for coal for heating in winter; moreover, the price of coal fluctuates quite widely across sample villages.

Fuels in rural areas are mainly used for heating, cooking, boiling water and cooking animal feed. In the sample, households spend about 6.5 hours per day using energy in winter, and more so in the colder Northern provinces, while in summer, energy is used daily for around 3.8 hours.[13] Across provinces and income levels, polluting solid fuels (coal, charcoal, fuelwood, crop residues) dominate energy consumption (Table 1). Although better-off households are more likely to use clean gaseous or electric fuels (LPG, biogas, and electricity), solid fuels nevertheless still represent around 70% of energy use for the richest (fourth) quartile (for simplicity, we aggregate fuels by the number of hours in which the fuel is used). They represent 80% of fuel use in the first (poorest) quartile. Overall, these statistics are consistent with other literature on energy use in rural China.[14] The high level of biomass and solid

[13] Because of the difficulty of comparing various fuels and of estimating the energy content of fuelwood, the different fuels and energy sources are aggregated by the number of hours per day in which they are used for cooking (more precisely, cooking food, boiling water, and cooking animal feed). They are further aggregated over summer and winter time (the households were asked to give the information separately).

[14] Jiang and O'Neill (2004) found that firewood, straw, and stalks remain the major sources of rural energy consumption for two-thirds of rural households. Li et al. (2005) reported that rural households in Yunnan mainly relied on firewood (41%), straw (12%), and coal (39%).

fuel use across income groups in rural China suggests that the income gradient for clean energy use in rural China is rather muted (Hao, 2005; Jiang and O'Neill 2004).

Furthermore, while there is a tendency for coal to play a relatively greater role in the fuel mix for better-off households, at 33 percent of the time of fuel use, fuelwood remains the most used fuel even in the richest quartile, despite the fact that it displays the largest income gradient (a 21 percentage point decline in going from the poorest to the richest quartile). These results confirm that income growth alone will not be sufficient to displace dirty solid fuels, closely mirroring findings in other studies of household energy switching in developing countries generally (Heltberg et al, 2000; Heltberg, 2004 and 2005; Cooke et al., 2008) and China in particular (Jiang and O'Neill, 2004). The dominance of solid fuels, even among households who should be able to afford alternatives, motivates our interest in energy technology interventions such as biogas that might help speed up the transition to cleaner and more sustainable energy use.

Interestingly, while the use of biogas is larger for the 2nd and 3rd quarter households, it is lowest in relative terms among the wealthiest. This is possibly linked with the move out of small animal husbandry as households get richer. It also positions smallholder biogas holding as a transitional rural fuel, especially in rapidly developing economies such as China.

Fuel use patterns also differ by location, both because of the temperature, as highlighted in the context of biogas, but also because of differences in the ease of buying coal and collecting fuelwood. In Hubei province, fuelwood and coal account for 52 and 32 percent of total energy use in winter, while in Hunan, they account for 35 and 42 percent respectively. In Anhui, Chongqing, and Guangxi, fuelwood and crop residues are the two most common fuels. Yet, biogas and other clean energy also accounted for a considerable share. In Guangxi and Hubei provinces, biogas comprises 23 and 13 percent of summer energy use, while electricity accounted for more than 10 percent in Anhui, Chongqing and Guangxi.

Sample households devote, on average, 10% of their expenditures on commercial energy (Table 2), with little difference across income categories (9.8 % for the poorest and 10.4 % for the richest quartile). There is virtually no commercial market for fuelwood and crop residues, so energy expenditures mainly comprise expenses on coal, electricity, and LPG. In addition, many people women in particular, but not exclusively—spend considerable amount of time collecting biomass fuels. For example, households in the first income quartile report spending 13 hours per month collecting fuelwood, at an average distance of 1.4 km from the house (Table 2). This is sizeable but less than some claims.

Against this background, what is the prospect for greater uptake of biogas and what is its potential for achieving health, economic, and environmental benefits? These questions are pursued in the remainder of the paper.

3 Descriptive Analysis Points to Substantial Benefits from Biogas Use

Cross-sectional data do not allow to control adequately for the fact that biogas adoption is non-random and that adopters may differ in systematic and unobserved ways from non-adopters. Nor do such data permit protection against the fact that the areas where biogas services are offered may systematically differ from those where it is not offered, which may in itself affect biogas adoption—the so-called “program placement effects” in econometric jargon. Fully cognizant of these limitations, the results below are not presented as proof of environmental, economic or health effects as such, but rather as indications that the popularity of biogas reported during our field visits and in personal conversations with other researchers studying biogas, may well be grounded in benefits felt on the ground.[15] Indeed, ninety-three percent of the biogas users observed in the sample during the first round reported to be satisfied or very satisfied with their system (3% are not satisfied).

Where possible, the robustness of the preliminary findings based on bi-variate analysis is further explored using multi-variate analysis. In particular, a series of observed household characteristics and village-level fixed effects are included to help protect against potential estimation bias from household heterogeneity and program placement respectively. The former does only provide partial protection, as it does not control for unobserved heterogeneity. The latter on the other hand helps overcome potential estimation bias from program placement effects, which might follow from non-random selection of villages into the (subsidized) biogas service program. As many renewable energy studies have had to rely on relatively small, purposively selected samples from a limited number of villages, they could often not properly control for placement effects or the village characteristics more broadly. Our study adds value also in its relatively larger and more diverse sample.

Environmental benefits

Bivariate comparison of energy use among biogas adopters and non-adopters suggests an important degree of fuel switching, with reported annual coal consumption almost 200 kg/per year lower among biogas adopting households than among non-adopting households (95 kg/year versus 290 kg/year). Adopters also tend to use less fuelwood and crop residues (respectively 157 kg and 347 kg/year less on average). These numbers are suggestive of substantial displacement of dirty fuels among biogas adopters. However, attributing causality to biogas adoption is complicated. Biogas users may for example also be richer and thus more likely to use other clean fuels even in the absence of biogas.

[15] To be more conclusive and ensure external validity, randomized experiments on a national scale are necessary. Given political constraints and ethical reservations, these have proven impossible to conduct so far in China (and elsewhere). Follow up analysis will focus on difference-in-difference methods paired with propensity score matching exploiting the multiple rounds of the data to generate more definitive conclusions about the welfare effects of biogas. The current findings nonetheless provide useful pointers to motivate the debate and follow-up analytical efforts.

To get a better (though still imperfect) sense of how the adoption of biogas affects the demand for fuelwood, crop residues and coal, the demand for each of these fuels (all expressed in log terms) was estimated in a multivariate setting. Following the literature, a series of household characteristics, such as the demographic and educational characteristics of the household, its possession of land, the main occupation of the household head and its reliance on remittance income were included. The demand equations were further augmented with village-level fixed effects to control for unobserved village level factors, including supply side factors such as the availability of a biogas program and support systems, the availability and price of the different energy sources, and the agro-ecological, socio-economic (opportunity cost of labor) and institutional environment, which may simultaneously affect the adoption of biogas and the demand for other fuels and induce biased estimates.

The equations are estimated using Ordinary Least Squares with village fixed effects and corrected for clustering at the village level. The results are reported in Appendix Table 1. The regressions suggest a statistically significant displacement by biogas of fuelwood (collection time and quantity), crop residues, and the share of all dirty fuels in the fuel mix. While the effect of biogas on coal use is also negative, at a t-value of 1.64 (=0.519/0.315) the coefficient on biogas is imprecisely estimated. The results also identify several demographic and wealth variables that influence the fuel mix in expected directions; for example, the more educated and the more wealthy households consume less dirty fuels overall, even though households in the richest quartile also consume more coal, as suggested by the bivariate analysis earlier on. Households with more land and livestock on the other hand, tend to use more fuel wood and crop residues and tend to have a higher share of dirty fuels in their energy mix.

Economic benefits

When it comes to economic and welfare benefits such as time savings and reduced agricultural input costs, adopters nearly unanimously (98%) said biogas saved them time in cooking, mostly women's time: women in households with biogas saved on average 1.2 hours per day in cooking time (median one hour). There were also some time savings for men and children, so the total household time saving for all biogas users was 1.7 hours per day. This is because gas is faster and easier to cook with compared to biomass alternatives.

Adopters also nearly unanimously (99% of biogas users) reported time savings from having to collect less of other fuels. Women in households with biogas reported time savings of 24 days per year on average, men saved 10, and children saved 4. Not only are these time savings quite sizeable, and welfare-enhancing in their own right, they are also suggestive of biogas inducing fuel switching away from biomass. One-quarter reported that their time savings were used for more leisure, while the remainder used it for household chores and income generating activities.

Biogas residues can be used as organic inputs on the farm: 77% of households with biogas used residues as fertilizer in the year prior to the survey, and almost all of those had been able to cut back on other fertilizers. Further, 79% had been able to reduce their use of insecticides as a result of applying biogas residues, and nearly all of them (96%) felt this had improved the quality of their crop.

Benefits on health

An increasing number of epidemiological studies are linking exposure to IAP from cooking with solid biomass fuels to various health outcomes such as acute lower respiratory infection, chronic obstructive pulmonary disease and lung cancer from coal smoke[16] and emerging evidence suggests that IAP also increases the risk of other child and adult health problems, including low birth-weight, peri-natal mortality, asthma, ear infections, tuberculosis, and other (WHO 2007).

The high risks combined with the large population of solid fuel users make IAP a major global public health issue. In 2000, indoor air pollution, mostly from stoves burning solid fuels, was responsible for more than 1.5 million deaths and 2.7% of the global burden of disease according to the World Health Organization (2007). A meta-analysis of China implicated IAP from solid fuel use in China as responsible for approximately 420,000 premature deaths annually, more than the approximately 300,000 attributed to urban outdoor air pollution in the country (Zhang and Smith, 2007). Although robust documentation of health effects is not the purpose of the research reported here, the data do suggest some adverse impacts of solid fuels on respiratory health, especially among the persons responsible for cooking.

Splitting the sample at the median of dirty fuel use (by time), we find that among those 50% of households that use dirty fuels the most, 42 percent reported coughing over the past year, compared to 34 percent of low users of dirty fuel in cooking (Table 4, numbers refer to the main person responsible for cooking in the household). Bringing up phlegm from the lungs, another indicator of possible respiratory illness, is also slightly more prevalent among high than low users of solid fuels (21 compared to 16 percent) and the same is found for wheezing or whistling in the chest (16 against 11 percent). Consistently, high users of solid fuels are more likely to have seen a doctor for one or several of these respiratory symptoms and report higher average medical expenses for this purpose. Similarly, children below the age of 14 were also more likely to have shown symptoms of cough last month (23 percent in high dirty fuel using households compared with 18 percent in low-dirty-fuel households). These results also appear to carry over to biogas per se, with only 20 percent of children in households having biogas

---

[16] Smith et al, (2000), Ezzati and Kammen (2001), WHO (2002), Duflo, Greenstone, and Hanna (2008), Pitt, Rosenzweig and Hassan (2010), Rehfuess, Bruce and Smith (2011).

reporting having coughed last month compared with 24 percent of children in households without biogas.

4 Biogas Uptake, Use, and Suspension

Given the supportive indications that biogas use has benefits for the environment, women's time use, economic welfare and health, we now examine which factors influence the uptake, use, and suspension of biogas. In the sample, 610 households (22.6%) have installed a biogas digester (as mentioned, biogas users were deliberately oversampled). A large majority (83%) of biogas users in the sample installed it during the last five years and 39% installed it during 2008-9. Ninety-three percent of biogas users are satisfied or very satisfied with their system (3% are not satisfied) which, taken together with the results reported above, is ground for optimism regarding the ability of biogas to deliver on at least some of the expected benefits.

Biogas uptake

After subsidies, installation of biogas costs households on average Yuan 1300 for materials and Yuan 530 in hired labor, equivalent to USD285. In addition, households reported spending on average 19 days of their own time on installation and repairs. This underscores that biogas is not suitable for all farm households, in particular not those with limited financial and labor resources. Rural Chinese households' responses about their reasons for *not* installing biogas reflect this. Responses (Table 5) centered often on lack of labor, inputs (42.5 percent), and animals (11 percent) required to operate the biogas digester, as well as on lack of financing for the installation costs (19 percent). About 16 percent also mentioned lack of space in the farmyard compound.

We use multivariate regression analysis to assess some of the factors that influence the biogas uptake decision (see Appendix A2). The dependent variable is the likelihood of having installed biogas and the explanatory variables include household demographic and socio-economic variables, while controlling for village characteristics, including factors affecting the supply of biogas supply services as well as the (implicit) price of other energy sources, through village dummy variables. Column 1 reports the results with village fixed effects, while column 2 adds village price and infrastructure variables directly instead, to explore how different village characteristics affect the uptake of biogas, including the year when biogas was first introduced in the village, access to road infrastructure, and the price of other energy sources.

Households raising animals are more likely to have biogas as compared to those who do not raise animals, as are those with larger families and with younger heads. This is consistent with the reported labor and animal shortages as key reasons for nonadoption. The dependency ratio does not have significant impact. The probability of adoption increases with income, while it decreases with the share of that income stemming from remittances, highlighting the importance of labor availability. Concerning the village characteristics, biogas adoption appears to respond positively to: the prices of coal and the average fuelwood collection time suggesting a substitution effect; village road infrastructure; and the number of years since biogas was first introduced in the village, pointing to some learning and a broadly positive experience among the adopters.

Use of biogas

Almost all (93%) households with biogas used it for cooking. For nearly all of them, the quantity of gas generated was sufficient or nearly sufficient to cover their needs during the summer. But during the winter, it was only sufficient for half of them (the colder temperatures during China's 2-3 winter months reduce the digestion speed). Only 60% of biogas adopters had received technical training in how to make best use of the biogas residues. Most of that training was delivered by government officials and most of the farmers who had received the training were fully or partly satisfied. However, only 64% of trainees were aware that biogas residues can also be used to soak the seeds before they are planted, suggesting some scope for further optimization of biogas utilization.

Suspension

Biogas, like other similar energy technologies, can be susceptible to problems with technical reliability and consumer acceptance. To sustain its benefits, it is vital to overcome such problems. National statistics indicate a high level of suspension. In 2007, of the 26.5 million biogas digesters installed in China's rural areas, only 60% were operating normally (Chen et al. 2010b), with some sort of problem affecting the remainder. The majority of the suspension nationally occurred during the first year after installation and appears to be rooted in poor follow-up services (Chen et al. 2010b).

Our data echo this to some extent, though with one important nuance. First, among those that have ever adopted biogas, 36% expressed that they had at some point stopped using it for some reason and most of them (78 percent) during the first year. However, the suspension was often temporary and not necessarily related to any flaw in the equipment, but more often than not, related to temporarily having too few animals, sometimes in combination with cold winter temperatures that slow down digestion (Table 6).

Thus, in this sample, suspension of biogas appears to be temporary and related to having too few animals at some point during the year. Two-thirds of the households reporting an incident of biogas suspension cite issues with insufficient quantity of gas and too few animals to supply the dung needed to keep the system operating. These two reasons (insufficient gas and too few animals) amount to the same, as the key reason for insufficient gas production is shortage of animals, in particular pigs, which supply the feedstock for the digester. Animal ownership fluctuates over the year, as it is customary to sell or slaughter pigs in winter in time for the Lunar New Year celebration and to restock a few months later. Among those reporting an incident of biogas suspension, one-quarter did not raise any animals and the remainder reported double as many days without pigs as the non-suspenders (110 days/year vs. 55 for non-suspenders).

In our sample, 11% of biogas users have experienced some technical problem with their system for a host of reasons. However, almost all of them were able to get their system repaired, mostly quite easily and at low cost (89% spent less than Yuan 100 on the repair, which was usually done by government-employed technicians). Delays until repairs may also account for some of the observed temporary suspensions. In addition, we observe that the suspension rate is higher among households who did not receive technical information and training on biogas use and maintenance (some 14% of adopters reported not receiving information, which is problematic given the relative technical complexity of the system). These findings suggest a need for careful targeting of biogas to households with a sufficiently large and stable pig holding and a role for training and information dissemination to potential adopters. They also suggest that the post-installation service work satisfactorily, at least in the sampled areas.

5 Conclusions

Clean and safe rural energy is an important component of green growth and sustainable development, with biogas a technology that appears to hold substantial promise. It is a renewable energy technology with beneficial by-products. It converts waste to useful energy, reduces greenhouse gas emissions, and reduces the need for solid fuels thereby spurring lower IAP and health gains as well as fuel collection time savings—benefits that disproportionately benefit women. Worldwide its uptake is nowhere near its potential, making it seem an easy win for sustainable development strategies. The key question is, therefore, how well does its record on the ground live up to its potential?

This paper provided a preliminary assessment of the experience with rural biogas in China, which is by far the country with the strongest record of biogas promotion. Using purposively collected data with a sample size of 2,700 households from 225 villages in 5 provinces, this paper found tentative ground for optimism. Rural biogas in the sampled areas of China appears to deliver on many if not all of its benefits. There was widespread awareness and acceptance of the technology with clear indications of benefits on the ground. These were: time savings from reduced fuelwood collection and easier cooking that disproportionately benefit women; indications of productive use of biogas' by-products; signs of partial displacement of fuelwood and crop residues in response to biogas adoption, with mixed indications regarding displacement of coal; and some suggestions of benefits to respiratory health.

Moreover, problems with suspension, whether due to technical or human factors, were not evident to a major degree, with suspension of short duration and most equipment breakdown getting repaired with modest delay and expense. This was refreshing and reassuring, given the uneven record of implementing household energy interventions in developing countries (for a recent overview, see Bruce, Rehfuess and Smith, 2011).

The findings in this paper contribute in important ways to discussions of rural energy and sustainable development. First of all, the findings identify (tentatively) a case of a successful sustainable household energy technology and suggest that China has been able to address some of the technical and managerial problems in its earlier biogas programs. Second, unlike much of the evaluation literature concerned with NGO-supported pilot programs, the findings reported here pertain to a program of massive, national scale—findings apply (potentially) to millions of households. Third, our sample is much larger than the sample used in most of the household energy studies that have conducted purposeful surveys, enabling us to control for placement and supply side effects. Fourth, our findings are rooted in a comprehensive analysis of fuel demand unlike some of the energy and development literature that has taken a more partial approach.

At the same time, some limitations, of the study and of biogas, need to be kept in mind. This study was based on cross-sectional data. It will be important to re-assess the findings in light of panel data using impact evaluation methodologies, something already planned. In this, health impacts should be given particular attention. While it seems clear that biogas can promote the reduction (but not the elimination) of other and more polluting biomass fuels, the health impacts proved difficult to identify with the currently available data. Better data on health and indoor air pollution will be required. The findings further suggest that biogas is not suitable for all farmers. The requirements for successful biogas adoption and operation are a sufficient number of penned animals; appropriate temperatures and preferably mild winters; and adequate financial resources to overcome liquidity constraints and make the upfront investment affordable. Many smallholder farmers meet these criteria, though still other energy and policy solutions will be needed for those rural residents who do not meet these requirements.

References

Bruce NG, Rehfuess EA and Smith KR. 2011. Household Energy Solutions in Developing Countries. In: Nriagu JO (ed.) Encyclopedia of Environmental Health, v 3, Burlington: Elsevier.

Chen, Y., Gaihe Yang, Sandra Sweeney, Yongzhong Feng, Aidi Huod. 2010a. An Assessment of the Availability of Household Biogas Resources in Rural China, *International Journal of Energy and Environment*, 1-5: 783-792.

Chen, Yu, Gaihe Yang, Sandra Sweeney, Yongzhong Feng. 2010b. Household biogas use in rural China: A study of opportunities and constraints, *Renewable and Sustainable Energy Reviews*, Volume 14, Issue 1, January 2010, Pages 545-549, ISSN 1364-0321, 10.1016/j.rser.2009.07.019.

Christiaensen, Luc. 2012. Food, Farms and Fields in China 2030 – The Role of Agriculture in a Modernizing Society, World Bank, mimeographed.

Cooke-St. Clair, P.C., G. Köhlin and W. F. Hyde. 2008. Fuelwood, forests and community management – evidence from household studies. *Environment and Development Economics*, 13: 103-135.

Duflo, Esther, Greenstone, Michael, and Hanna, Rema (2008), "Indoor Air Pollution, Health and Economic Well-being". MIT, February 2008.

Ezzati M, Kammen DM. 2001. Quantifying the Effects of Exposure to Indoor Air Pollution from Biomass Combustion on Acute Respiratory Infections in Developing Countries. *Environ Health Perspect* 109(5): doi:10.1289/ehp.01109481

Heltberg, Rasmus. 2004. Fuel switching: Evidence From Eight Developing Countries, *Energy Economics*, Volume 26(5): 869-887, 2004.

Heltberg, Rasmus. 2005. Factors determining Household Fuel use in Guatemala. *Environment and Development Economics*, 10: 337-361, 2005.

Heltberg, Rasmus, C. Arndt, and N. U. Sekhar. 2000. Fuelwood Consumption and Forest Degradation: A Household Model for Domestic Energy Substitution in Rural India. *Land Economics*, May 2000: 213-232.

Ho, Mai-Wan. 2005. Biogas Bonanza for Third World Development, *Science in Society* No. 27.

IEA. 2011. World Energy Outlook 2011

Jiang, Leiwen and Brian C. O'Neill. 2004. The energy transition in rural China, *Int. J. Global Energy Issues*, Vol. 21, Nos. 1/2, 2004.

Köhlin, Gunnar, Erin O. Sills, Subhrendu K. Pattanayak, and Christopher Wilfong. 2011. Energy, Gender and Development: What are the Linkages? Where is the Evidence? *World Bank Policy Research Working Paper 5800*.

Mark M. Pitt, Mark Rosenzweig and Nazmul Hassan. 2010. Short- and Long-Term Health Effects of Burning Biomass in the Home in Low-Income Countries. Processed.

Parawira, W., 2009. Biogas Technology in Sub-Saharan Africa : Status, Prospects and Constraints, *Review of Environmental Science Biotechnology* 8: 187-200.

Rehfuess EA, Bruce NG and Smith KR. 2011. Solid Fuel Use: Health Effect. In: Nriagu JO (ed.), Encyclopedia of Environmental Health, v 5, Burlington: Elsevier.

Reuters News, 2011, China's corn rush to redraw global food landscape, *Reuters News*, 3 October 2011.

Smith, K.R., J.M. Samet, I. Romieu, and N. Bruce (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax*, 55(6): 518-532.

World Health Organization. 2007. "Indoor Air Pollution: National Burden of Disease Estimates". Geneva.

World Bank 2008, Project Appraisal Document on two proposed loans in the total amount of US$120.0 million to the People's Republic of China for an Eco-farming Project, Report No: 39781-CN.

World Bank, 2007. World Development Report 2008: Agriculture for Development, The World Bank: Washington D.C.

Zhang J and Smith KR. 2007. Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions. *Environmental Health Perspective* 115:848–855.

Zhang, X., J., Yang, and S., Wang. 2012. China Has Reached the Lewis Turning Point, *China Economic Review*, forthcoming.

Zheng Yisheng, Yang Minying, & Shao Zhen. Undated. Rural Energy Policy in China. Research Group of Energy Policy, Institute of Quantitative and Technical Economics, Chinese Academy of Social Sciences. Available online at http://iis-db.stanford.edu/evnts/3920/ZHENG_paper.pdf

Table 1: Solid fuel use continues to dominate rural energy use, even among the richer quartiles.

time spent using different fuels (% of total fuel time use)			Dirty energy				Clean energy			**All fuels**
Income quarter	Coal	Charcoal	Fuelwood	Crop residues	All dirty fuels	LPG	Biogas	Electricity	All clean fuels	
First	14.8	0.3	54.5	10.7	80.3	3.0	7.2	9.4	19.7	100
Second	16.9	0.3	45.4	15.2	77.7	3.5	9.1	9.8	22.3	100
Third	18.0	0.1	41.0	17.3	76.5	5.3	7.7	10.5	23.5	100
Fourth	24.2	0.1	33.4	13.0	70.6	10.7	5.3	13.4	29.4	100
All (n=2413)	18.5	0.2	43.6	14.1	76.3	5.6	7.3	10.8	23.7	100

Table 2: Households spend on average around 10 hours collecting fuel wood, and more for the poor.

Quartile of per capita income	Distance to collect fuel wood (km)	Duration of collection trip (hours per trip)	Trips per month (number per month)	Average time per month spent (hrs)	Share of total expenditures devoted to energy (%)
1	1.2	2.9	4.4	12.8	9.8
2	1.2	2.9	3.4	9.9	8.6
3	1.1	2.7	3.1	8.2	10.2
4	1.0	2.8	2.8	8.0	10.4
Total	1.1	2.8	3.5	9.9	9.7

Note: based on 1899 households reporting non-zero fuelwood collection time

Table 3: Average use of coal, fuel wood and crop residue less among biogas users.

Average use per year	Whole sample	with biogas	without biogas
Coal (kg)	246	95	290
Charcoal(kg)	29	38	26
Fuelwood (kg)	2721	2599	2756
Crop Residues (kg)	793	524	871
LPG (kg)	12	12	12
Electricity (in hours)	362	390	354
Biogas (in hours)	-	535	-

Table 1: Among adults age 14 and above mainly responsible for cooking, high users of dirty fuels are more likely to report respiratory ill-health and related adult health-seeking behavior

Symptom / behavior (%)	**dirty fuel use**	
	low user	high user
***Main cook* (over the past year)**		
Couch last year (yes) (%)	33.9	42.0
Brought up phlegm from the lungs (yes) (%)	16.0	21.3
Had wheezing or whistling in chest (yes) (%)	11.3	16.3
Saw doctor for any of these symptoms (yes)	23.7	35.9
Cost of medical expense for seeing doctor (Yuan per visit)	432	614
Children (last month)		
Cough last month (yes) (%)	18.0	22.8

Note: dirty energy refers to use of coal, charcoal, fuel wood, and crop residues in cooking. The table splits the sample into “low” and “high” users” whose use of dirty fuels is below or above the median of dirty fuel use aggregated by time respectively.

Table 5: Non-adopters frequently mention lack of financing and labor inputs as reason.

Reasons for households who did not install the biogas digesters	**Freq.**	**Percent**
Not easy to use	63	3.6
The risk of fire and exploration	6	0.3
Have not heard about biogas	25	1.4
Could not get financing	340	19.3
Too many inputs/too much labor required to operate	533	30.2
Smell	6	0.3
Do not have enough animals supplying manure	190	10.8
Do not have space for the digester	276	15.7
Do not have enough laborers	220	12.5
Other	104	5.9
Total	1,763	100.0

Table 6: The major reason for suspension appears the lack of feedstock.

	Freq.	Percent
Too little gas generated	67	44.7
Possess too few animals	32	21.3
Technical problem with stove or digester	27	18.0
Inconvenient to use	2	1.3
Smell	2	1.3
It requires too much efforts to keep system running	3	2.0
Others	7	11.3
Total	150	100

Appendix: Regressions

Table A1: Correlates of fuel use

	(1)	(2)	(3)	(4)	(5)	(6)
OLS with village fixed effects	Log fuelwood collection time	Fuelwood used (annual qty), in log	Crop residues used, in log	Coal used (qty), in log	Share of dirty fuels in summer, in %	Share of dirty fuels in winter, %
HHold has biogas? (dummy)	-0.609***	-0.761***	-0.456*	-0.519	-32.34***	-17.73***
	(0.230)	(0.240)	(0.250)	(0.315)	(1.958)	(1.901)
Log hh size	0.0452	0.289	0.690***	0.994***	-0.970	-2.049*
	(0.221)	(0.240)	(0.229)	(0.264)	(1.523)	(1.191)
Age of hhold head, log	0.888**	1.275***	-0.137	-0.762*	5.555**	3.701*
	(0.380)	(0.403)	(0.385)	(0.390)	(2.702)	(1.968)
Male hhold head	0.219	0.354	-0.177	0.822**	1.717	2.591
	(0.288)	(0.380)	(0.355)	(0.368)	(2.437)	(1.617)
Average education of members, years	-0.0925**	-0.0902*	-0.140***	-0.00948	-1.012***	-0.487*
	(0.0412)	(0.0506)	(0.0437)	(0.0491)	(0.298)	(0.270)
Dependency ratio	-0.307	-0.512	-0.386	0.288	-2.350	-2.443
	(0.287)	(0.358)	(0.359)	(0.373)	(2.494)	(2.023)
Head is farmer	0.538**	0.363	0.0264	-0.358*	1.979	1.491
	(0.237)	(0.258)	(0.219)	(0.208)	(1.542)	(1.304)
Cultivated land, log mu	0.165***	0.131*	0.212***	-0.00175	1.138***	1.240***
	(0.0582)	(0.0696)	(0.0516)	(0.0436)	(0.366)	(0.321)
Raised livestock (dummy)	1.440***	1.668***	0.854***	-0.161	9.428***	7.537***
	(0.325)	(0.408)	(0.286)	(0.195)	(2.185)	(2.028)
2nd income quartile	-0.301	-0.563**	0.232	0.322	0.678	-2.168**
	(0.192)	(0.223)	(0.225)	(0.261)	(1.156)	(0.974)
3rd income quartile	-0.157	-0.470*	-0.233	0.400	-4.286***	-4.527***
	(0.218)	(0.252)	(0.241)	(0.251)	(1.478)	(1.203)
4th income quartile	-0.674**	-1.112***	-0.351	0.474*	-7.120***	-6.900***
	(0.264)	(0.317)	(0.263)	(0.279)	(1.830)	(1.411)
Remittance rec'd share of total income, %	0.201	0.610	0.152	-0.365	1.897	3.135**
	(0.309)	(0.376)	(0.306)	(0.306)	(1.799)	(1.428)
Constant	-5.974***	-1.791	-1.625	-1.345	56.51***	68.94***
	(1.453)	(1.651)	(1.611)	(1.614)	(10.67)	(7.382)
	2656	2635	2635	2635	2378	2375
	0.059	0.049	0.029	0.019	0.247	0.151
	216	216	216	216	201	201

Robust standard errors corrected for clustering in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A2: Correlates of biogas adoption

Household has biogas	(1) Village fixed effects	(2) Probit	(3) OLS
Log hh size	0.088	0.607	0.124
	(4.40)**	(5.22)**	(4.51)**
Age of hhold head, log	-0.051	-0.569	-0.134
	(1.77)	(3.12)**	(2.69)**
Male hhold head	0.011	0.111	0.029
	(0.36)	(0.75)	(0.88)
Average education of members, years	0.003	0.029	0.005
	(0.89)	(1.39)	(1.12)
Dependency ratio	-0.036	-0.160	-0.004
	(1.27)	(0.96)	(0.10)
Head is farmer	0.024	0.183	0.039
	(1.28)	(1.79)	(1.57)
Cultivated land, log mu	-0.001	0.014	0.002
	(0.32)	(0.58)	(0.45)
Raised livestock (dummy)	0.096	0.423	0.086
	(3.71)**	(2.59)**	(2.55)*
2nd income quartile	0.045	0.221	0.069
	(2.54)*	(2.73)**	(2.98)**
3rd income quartile	0.069	0.209	0.057
	(3.46)**	(2.15)*	(2.12)*
4th income quartile	0.073	0.032	0.020
	(3.28)**	(0.28)	(0.71)
Remittance rec'd share of total income, %	-0.037	-0.555	-0.129
	(1.69)	(3.58)**	(3.70)**

Household has biogas	(1) Village fixed effects	(2) Probit	(3) OLS
Biogas was introduced in village		1.751	0.171
		(6.23)**	(5.11)**
Years since biogas was first introduced in village		0.018	0.006
		(2.66)**	(2.43)*
Village has road		0.262	0.060
		(1.71)	(1.57)
Coal unit price, log		0.404	0.091
		(1.97)*	(1.82)
Fuelwood aver. collection distance, log		0.250	0.067
		(2.02)*	(2.13)*
Constant	0.144	-1.705	0.292
	(1.25)	(2.12)*	(1.38)
Observations	2656	2646	2646
Number of villages	216		
R-squared	0.03		0.15

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1