Domestic biogas in a changing China

Can biogas still meet the energy needs of China's rural households?

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Executive summary

Biogas development in rural China is at a crossroads. Following a decade of expansion aided by heavy government investment, around 100 million people in rural households now benefit from biogas digesters to provide clean cooking fuel and organic fertiliser. However, emerging problems call into question whether or not domestic biogas is able to meet the increasing energy needs of rural households, and how government subsidies to fund this technology can be more cost-effective.

Rapid economic development and urbanisation across the country have brought major changes to the rural setting and have made a significant impact on household biogas production. Fewer animals are kept as livestock in rural households, meaning less manure to feed into biogas digesters, and migration to cities means less available labour to operate them. Other difficulties include inadequate technical services for post-installation maintenance and repair, and the biogas digesters' financial performance, which is not always satisfactory. These combined factors have resulted in a large number of biogas digesters either functioning below their full potential or being out of use altogether.

This paper examines these emerging questions and challenges, and considers how they can be addressed in order to support the future development of a sustainable biogas sector. It finds that:

Biogas technology has clear economic, social and environmental benefits for rural households, such as reducing environmental pollution by safely recycling manure and providing households with a clean cooking fuel alternative to fossil fuels or firewood. These benefits motivated the government's huge expansion programme from 2003, leading to a cumulative investment of USD 4.5 billion by 2012 from government sources alone, and reaching a quarter of all rural households with biogas technology.

Some reports show a low rate of biogas digester use. One study found only 37 to 69 per cent of an area's digesters in normal use, though reports vary widely (others have found over 90 per cent). The reasons given for low rates of use have included lack of feedstock, lack of labour and inadequate maintenance.

Cost-benefit analyses for household biogas digesters have mixed results. Some reported findings that digesters represent a direct saving for households are based on questionable assumptions. With all parameters considered, the direct economic benefits of a domestic biogas digester may not necessarily exceed its costs over the expected lifecycle.

Funding for biogas development comes from a range of public and private sector sources, including central government, provincial government, government agencies, and international players such as the World Bank and the Asian Development Bank. Investment in domestic biogas is mainly via subsidies such as cash grants to households, construction materials, biogas appliances, and technician services.

The paper explores rural households' attitudes to investing in biogas digesters; whether they are willing and able to do so depends on a variety of economic, social and technical factors. For some households below the middle-income level, a digester is unaffordable, even with subsidies.

Key recommendations

After a decade of rapid development in the biogas sector, it is high time to review the problems that have emerged, and adjust strategies in response to changing circumstances. A 'business as usual' approach will not minimise the risks associated with the government's massive investment in this area.

Tackle the current problems

Problems to prioritise are the normal utilisation rate of biogas digesters, and their routine operation and maintenance:

- **Analyse the biogas sector objectively.** Despite the recent impressive expansion in scale, a comprehensive evaluation of the sector's performance has not yet been carried out. Significant data gaps must be filled, particularly on the quantified economic costs and benefits of biogas digesters, to confirm whether government subsidies are justified. Political will is needed to encourage an objective, unbiased analysis.
- **Measure the normal utilisation rate of rural digesters accurately.** Reports of the proportion of digesters in normal use vary between less than 30 per cent and over 90 per cent. Field studies must have a clear definition of 'normal utilisation rate', to make sure that results from different sources are compatible. Studies should include factors like the *actual* daily biogas production versus the *potential* daily production, and what proportion of a household's daily and annual cooking fuel needs are met by the biogas produced.
- **Improve the service and maintenance of digesters.** This lack is a major stumbling block in rural households' ability and willingness to use biogas. One possible solution is for public and/or private 'social biogas services' to carry out all or part of digesters' operation, maintenance and trouble-shooting. But adequate market competitiveness is crucial to make these services a viable business. The initial establishment of national rural biogas service networks is a starting point, and some post-installation service models have been developed, but longer-term trials are needed to evaluate their effectiveness and sustainability.

Make subsidies more cost-effective

There are concerns about how cost-effective the current subsidy scheme is. For instance, biogas digesters are still eligible for government subsidies if they run far below their full potential or even if abandoned shortly after installation. The assumptions used for the economic assessment of domestic biogas digesters need to be reviewed to confirm the justification of continuing government subsidies. Possible alternatives to explore include:

- **Performance-based subsidies** linking payment of subsidies to the performance of the installed biogas digesters. Service delivery could be contracted to biogas companies, which would pre-finance the project from their own capital or concessionary loans. Only after the service has been satisfactorily delivered and verified would companies be reimbursed by the government.
- **Use-based subsidies.** Rather than subsidise the installation of digesters, the government could provide various cash rewards to biogas user households, if the actual amount of biogas used within a year reached certain levels. Pilot projects of this scheme showed a 10 per cent improvement of digesters' normal utilisation rates.
- **Smart subsidies.** Smart subsidy schemes used by sectors such as agriculture, water supply, public housing, and rural telecommunications could offer inspiration to China's domestic biogas programme. Well-designed subsidies should be able to catalyse systemic change and accelerate the adoption of technology without distorting the target beneficiaries' behaviour.

Enhance the pro-poor component of biogas development

The current subsidy schemes do not address income disparities within a region or community, leaving poor and lower-income households unable to afford the construction of biogas digesters; yet they may be the best-placed to supply the necessary labour and feedstock to maintain a digester. Pro-poor arrangements should be explored, such as more grants for low-income households, or more effective social biogas services, or improved technical support.

Biogas is still an appropriate technology for rural areas of China, as this briefing demonstrates, though the sector needs a review and a shake-up. The experience of China can also help in understanding some of the challenges and opportunities offered by the biogas sector to developing and emerging economies across the world. If the majority of these rural populations were to shift their primary energy supply from local renewable energy sources to commercial fossil fuels, it would have a huge economic and environmental impact, affecting the security of energy supplies at a national or even global level. For this reason, due efforts should be made – in China as elsewhere – to overcome the various barriers to a robust and sustainable development of the biogas sector globally.

1
An overview of China's biogas sector

1.1 Official figures update

China's biogas sector has experienced significant change in the last decade. There have been changes in the scale of government investment; the growing number of domestic biogas digesters (see Figure 2) and larger-scale biogas plants; the emergence of post-installation services; and rapid urbanisation affecting rural areas across the country. Figures from the Ministry of Agriculture show that biogas users in China had reached 41.68 million households by the end of 2011, including 39.96 million households with domestic biogas digesters. Biogas households accounted for 23 per cent of total households in rural China or about one third of the rural households suitable for biogas installation.[1] With the financial support of the government, 24,000 small biogas plants and 3690 medium and large biogas plants[2] had been installed (MoA, 2012d), supplying biogas to 1.7 million households. The government aims to have 50 million biogas user households in rural China by 2015, or around half of all rural households suitable for biogas installation (NDRC, 2012).

Box 1.
What is a domestic biogas digester?

'Biogas digesters' allow rural households with livestock to convert manure and other organic waste into **'biogas'** for cooking fuel and **'bio-slurry'** as fertiliser. **Digesters** tend to be underground, airtight containers with a capacity of four to 20 cubic metres. **'Feedstock'** (the organic waste) is emptied into the digester, where a consortium of bacteria act on it anaerobically, breaking down the waste into gas and slurry. Pipes convey the biogas directly to the household kitchen, and the bio-slurry can be discharged regularly for use as a fertiliser. One cubic metre of biogas will provide about two hours' cooking time.

1.2 A history of domestic biogas development

The development of domestic biogas in China has had some ups and downs in its 80-year history. Efforts to pioneer biogas in China can be traced back to the 1930s, with a few companies trying to commercialise biogas as an alternative to imported kerosene for lighting. The

1 Rural households deemed suitable for biogas installation must meet the following criteria: 1) enough animal waste to feed the digester – minimum three pigs or one cow in stock; 2) enough ground space in the home yard for biogas construction; 3) adequate management capacity – minimum one adult labourer at home; and 4) appropriate self-financing capacity.

2 The industrial standard of China (NY/T667-2011) defines as 'small scale' biogas plants with a digester volume of 20–300m^3 per unit or a daily biogas production of 5–150m^3; those with unit digester volume of 300–500m^3 or a daily biogas production of 150–500m^3 as 'medium scale', and those with unit digester volume at 500–2500m^3 or an accumulative daily biogas production of 500–5000m^3 as 'large scale'.

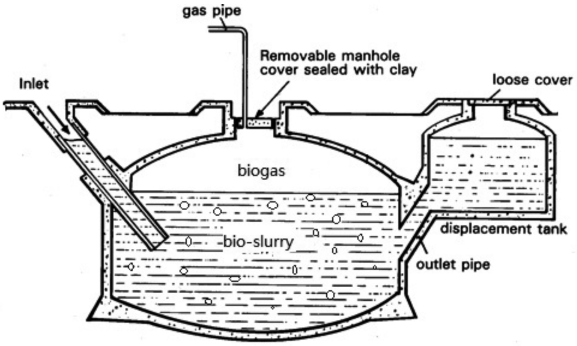
first official campaign to promote the technology started in 1958, when thousands of low-cost biogas digesters were constructed. While the initial results were encouraging, most of these installations were discarded a few years later, primarily due to problems caused by low-grade construction materials. Cement was in scarce supply at the time, and instead the so-called 'trinity mixture fill' was widely used, consisting of clay, lime, and sand.

In late 1970s, a severe fuel crisis across the country prompted another mass campaign for biogas construction and millions of household-scale biogas digesters were constructed.[3] Like the installations in the 1950s, these had a functional life of only one to five years due to various deficiencies in quality. Although the total number of domestic biogas digesters increased from 6000 in 1970 to 7.23 million in 1980, almost all the biogas digesters constructed during this period had dropped out of regular use by the mid-1980s, taking the digesters still in use down to 4.53 million by 1986 (MoA, 2007a). Nevertheless, these early efforts significantly contributed to the development of biogas technology. The traditional design of domestic biogas digesters with a fixed dome and a hydraulic chamber are now commonly referred to as the Chinese fixed-dome type (see Figure 1) and promoted in developing countries by many organisations worldwide, with some modifications.

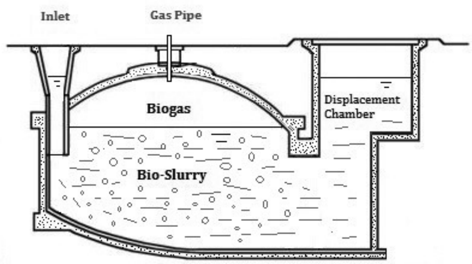
Lessons learned in the 1950s and 1970s campaigns led to improved design and construction materials (bricks and cement or concrete) in the 1980s national rural biogas programme. Growth in the total number of domestic biogas digesters was slow between 1983 and 1998, probably due to low government investment and as a reaction to problems with the 1970s domestic biogas promotion. During this period, various national biogas standards were issued and different biogas systems[4] were designed, such as the integrated biogas-pigsty-toilet model, the pigsty-biogas-fruit model, and the biogas-toilet-pigsty-greenhouse (four-in-one) model (see Section 4.3 for more detail). Different uses of biogas and bio-slurry were explored and advanced biogas cooking and lighting

Figure 1.
Traditional and modified fixed-dome biogas digesters

Traditional biogas digester



Example of a modified biogas digester



Sources: (on left) Fraenkel (1986); (on right) Image courtesy of Zhang, W., China

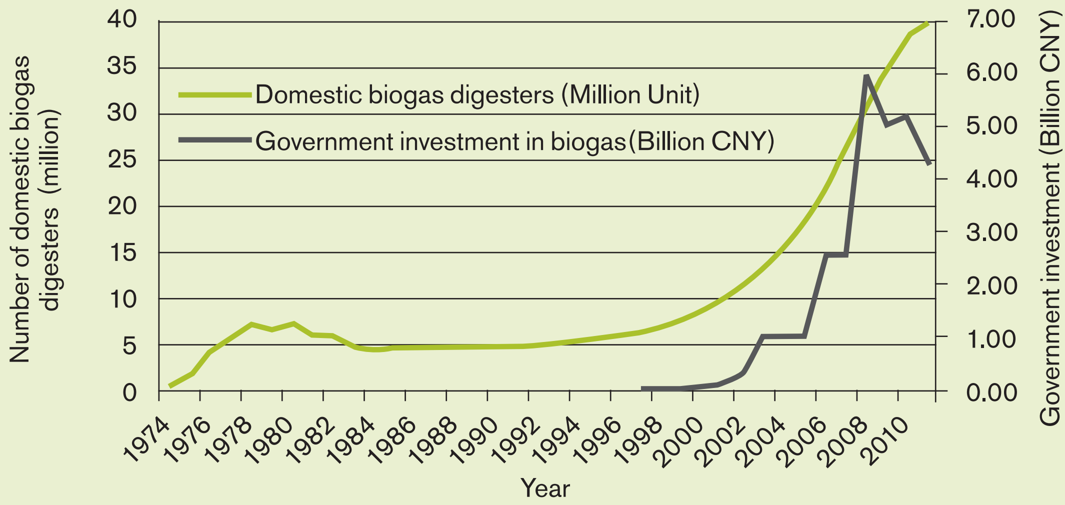
3 Domestic biogas digesters or household-scale biogas digesters refer to those with a digester volume of less than 20m^3, mostly at 6, 8 or 10m^3, mainly used by individual households.

appliances were developed. In addition to the conventional use of biogas, experiments were carried out using biogas for small-scale power generation (a few kW) and atmosphere control for grains or citrus storage. Bio-slurry was tested for effectiveness in seed soaking (germinating rice seeds by soaking them in bio-slurry), mushroom cultivation, fish food, and fruit and vegetable fertilising.

1.3 New developments with increased government investment

2003 was a turning point for China's domestic biogas development thanks to a significant increase in government investment. With funding from treasury bonds, annual investment in the national rural biogas programme reached a historical high of over one billion Chinese Yuan (CNY), roughly corresponding to USD 124 million[5] (at 2003 exchange rates). The government investment in biogas sector kept growing until it reached CNY 6 billion (USD 863 million) a year in 2008. Meanwhile, large and medium scale biogas plants for cattle farms started growing rapidly. Greater investment in the biogas sector also stimulated the active involvement of both public and private sectors. As of 2011, there were more than 40,000 people working at around 13,000 biogas promotional institutions at provincial, county, and township levels. Over 2000 biogas enterprises across the country employed more than 30,000 people and achieved a total output value of CNY 8 billion (CAREI, 2012). The total number of domestic biogas digesters in use over the years and the annual government investment in biogas programmes are shown in Figure 2.

Figure 2. Number of domestic biogas digesters and government investment in biogas, China (1974–2011)



Note: biogas digester figures are cumulative, while investment figures are annual.
Source: Li (2012); Hao (2011); Wang, Tu, and Chen (2012).

4 Biogas 'system' refers to not only the biogas digester, but integrated 'upstream' and 'downstream' connections as well (see Section 4.3).

5 The yearly average exchange rate of USD to Chinese Yuan (CNY) changed from 8.3 in 2003 to 6.3 in 2012.

The Chinese government's promotion of biogas technology is probably motivated by the need to address the following problems in rural areas: lack of clean cooking fuels; indoor air pollution from burning solid biomass (such as firewood) in poor cooking stoves; water pollution and water-borne infection from human and animal waste; soil degradation due to the wide application of inorganic fertilisers; and forest deterioration caused by the over-collection of firewood, among others. The national biogas programme provides two effective solutions to the problems described above: 1) it minimises environmental pollution in rural areas through the appropriate disposal and recycling of animal waste and agricultural residues, and 2) it provides rural households with a clean cooking fuel alternative.

1.4 Emerging problems and arguments

The primary goal of promoting biogas technology in rural China now seems to have shifted from energy recovery to environmental protection. Its application is no longer limited to household-scale biogas production for cooking and lighting, and bio-slurry for fertiliser, but extends to larger-scale biogas plants for the disposal of livestock waste and other organic waste. Gas produced from these larger-scale biogas plants may be used for power generation and/or distributed to households through pipelines. Nevertheless, domestic biogas digesters are still a major component of China's national rural biogas programme, particularly in less developed or poverty-stricken areas.

The rapid increase in the number of domestic biogas digesters has caused some growing pains. One major concern in recent years is biogas digesters' 'utilisation rate', or the proportion of digesters that remain in regular use after installation. Official sources indicate that around 85 per cent of domestic biogas digesters are in normal use,[6] about 10 per cent were out of use or only used occasionally, and around 5 per cent were discarded[7] each year (MoA, 2009b). The Ministry of Agriculture's latest report shows that 91 per cent of the domestic biogas digesters constructed between 2008 and 2010 were in normal use, based on spot checks of 757 sample households from 18 provinces (MoA, 2012a). However, other surveys at village, township and county levels reported much lower rates of use. A field study in Guizhou Province, southwest China, found that normal utilisation rates of domestic biogas digesters were between 37 and 69 per cent across various villages (Ding & Zheng, 2013). An investigation in Shaanxi Province sampling 4757 households found that 68 per cent of domestic biogas digesters were in normal operation and 19 per cent only used occasionally; the householders' main reasons were a lack of capacity or skills to carry out maintenance, lack of labourers to carry out the maintenance, and lack of feedstock (Dong *et. al*, 2012). Another investigation in the same province reported a normal utilisation rate of 61.4 per cent based on a sample of 1609 households in 10 counties (Wang, 2011). The most negative report so far came in a 2009 *China Economic Weekly* article, which reported that over 90 per cent of the domestic biogas

6 The Ministry of Agriculture defines 'biogas utilisation rate' as the percentage of 'in normal use' biogas digesters in the total sampled number, where 'in normal use' is interpreted as 8 months in use in the south region, or 6 months in use in the north region or high elevation areas (1800 metres above sea level) (MoA, 2011).

7 For statistical purpose, domestic biogas digesters that meet the following criteria may be reported as unserviceable for discard: 1) over 20 years of normal use; 2) damaged by natural disasters and beyond repair; 3) no longer operational due to moving home or other reasons (MoA, 2013).

digesters built in the previous three years were discarded in some villages in Heilongjiang Province in northeast China (Cui & Ma, 2009). An audit on a biogas project under the Treasury Bonds For Rural Biogas Construction Programme in a county of the same province found that 55 per cent of the sampled biogas digesters were not in use and 18 per cent were discarded (Wang, Jin, & Wang, 2011). Also, social biogas services were found to be lagging behind, which severely affected the development of the rural biogas industry (CASST, 2008). Obviously, these reports call into question the cost-effectiveness of government subsidies for domestic biogas, and whether biogas is effective in meeting the needs of rural households.

New problems for biogas development have emerged with rural China's rapid urbanisation and socio-economic development. Problems include a lack of manure, as traditional animal husbandry at individual households gives way to centralised livestock farms; the increased cost of rural labourers and their migration from villages; and the availability of modern household energy options, namely liquefied petroleum gas (LPG) and electricity. On the other hand, there are also new opportunities for biogas development, such as a growing awareness of the advantages of using decentralised renewable energy sources; the initiation of rural biogas service networks; the mass production of prefabricated fibreglass-reinforced plastics biogas digesters; ongoing efforts towards technical innovations, improved fermentation processes, and new materials; as well as the government's continued commitment to pro-poor development. These positive changes may lead to increased government investment in the national biogas programme, and more importantly, greater willingness and ability among targeted rural households to pay for the installation of digesters, and to operate and maintain them adequately. Together, these factors could create a robust and sustainable biogas sector in China.

2
Costs and benefits of domestic biogas digesters

Data sources from the Ministry of Agriculture show that the annual production of biogas in China is currently more than 15 billion cubic metres, roughly corresponding to 25 million tonnes of coal or 11.4 per cent of the country's total natural gas consumption. These biogas digesters each year produce 410 million tonnes of organic fertilisers, reduce carbon dioxide emissions by 61 million tonnes, and generate benefits worth CNY 47 billion from cost savings and income growth (MoA, 2012c). By comparison, the total government investment in the biogas sector, together with contributions from beneficiary households towards installation, was estimated at CNY 91.8 billion (MoA, 2013). The national biogas programme still has too many data gaps for a thorough economic analysis, such as the operational and maintenance costs of biogas digesters and the quantified indirect benefits. Nevertheless, an analysis of individual cases may help better quantify the cost-effectiveness of biogas digesters.

Most biogas digesters for household use have a digester volume of 6, 8, or 10 cubic meters and are designed to last for 20 years. Figure 3 shows a typical domestic biogas digester under construction in a rural setting. The cost and benefits of biogas digesters vary across the country, from the industrialised coastal region in eastern and southern China to the agricultural plain areas in the central region and the mountainous and remote areas in the western region. Variations include the market price of construction materials and alternative cooking fuels, the cost of labour, and environmental conditions (such as temperature) that affect biogas productivity.

2.1 Costs

The cost of a domestic biogas digester falls into two categories – construction and operation. The construction cost has three major components: 1) materials (cement, sand, gravel, bricks, steel rods and wire, and coatings); 2) excavation and construction (technician service, labour, and steel mould used to cast concrete);[8] and 3) gas appliance parts (pipeline and valves, gas pressure gauge, desulphuriser, gas cooker, and gas lamp). Government data show that the total construction cost of an eight cubic metre biogas digester is usually within the range of CNY 2250 to 4850 across all provinces, with a mean value of around CNY 3,000 (USD 485) (MoA, 2007a) (MoA, 2012b). This figure probably approaches the higher end in both the well-developed areas, due to higher labour costs, and also the least-developed remote areas, due to the higher prices and transportation costs of construction materials.

Operational costs also have three major components: 1) feedstock (collection, preparation, and/or purchase); 2) maintenance (feeding, discharge); and 3) repair or replacement of parts (gas pressure gauges, pipeline and valves, cooker spare parts and lamp mantles). However, there are major difficulties in calculating operational costs. The first problem is that there is no commercial value for manure or other feedstock generated by

8 This mould would last for the construction of perhaps 100 digesters, and each construction process would depreciate its value, so 'mould depreciation' is another cost to take into account.

Figure 3.
Domestic biogas digester under construction, Yunnan Province

Photo credit: Xia Zuzhang (2005)

individual households; yet its value cannot simply be ignored. Where households have fewer livestock, for example, and therefore not enough manure for the biogas digester, the cost of buying in feedstock may not be worthwhile merely to produce biogas as a cooking fuel. Another difficulty is the actual amount of labour and the cost of labour; in the past, the cost of sufficient labour to operate and maintain digesters was taken for granted. Now that the cost of rural casual labour has increased significantly, it must be included in any estimate of the overall cost. In fact, the shortage of both manure and labour have been recognised as major challenges to the normal use of domestic biogas digesters in many parts of rural China.

Finally, the subsidised and real costs for services provided by the national rural biogas service network must also be taken into account.

In addition to the items needed to construct and operate a biogas digester mentioned above, a few other factors should be taken into consideration which are easily overlooked; such as the price of land for biogas construction; the risk of bad odours, mosquitoes and flies, if the biogas digester fails to function normally in the hot season; the cost of backup solutions when there is not enough biogas to meet cooking needs in full; and the potential risk of suffocation to anyone attempting to repair the digester from the inside without following safety instructions.

2.2 Outputs and benefits

The direct outputs of domestic biogas digesters are biogas and bio-slurry. The main *direct* benefits are the fertilising properties of bio-slurry, better waste management, and the killing of pathogens during the anaerobic fermentation process. Commonly quoted *indirect* benefits of biogas technology include better environmental hygiene; fewer occurrences of respiratory and intestinal diseases; improved soil fertility and agricultural productivity; less pressure on forest ecosystems due to less demand for firewood; less time used collecting firewood and cooking; better energy security due to using diverse energy sources and relying less on fossil fuels; and less greenhouse gas emissions. While these indirect benefits are important and should be included in any economic analysis, from the perspective of individual households they are external concerns, and concrete, quantified financial or economic data are rarely available.

A recent World Bank report on biogas use in China collected data from 2700 households in 225 villages in five provinces. Though the report did not set out to offer proof of biogas's environmental, economic or health benefits, it offered tentative grounds for optimism, as domestic biogas in the sampled areas appeared to deliver on many of its promises. There were clear indications of time saved by needing less firewood, and easier cooking, which disproportionately benefits women; the productive use of bio-slurry; the partial displacement of firewood, crop residues, and chemical fertilisers as a result of adopting biogas, with mixed results in terms of replacing coal, which is mostly used in winter; and some signs of benefits to respiratory health (Christiaensen & Heltberg, 2012).

From an economic perspective, the public benefits of biogas digesters' various impacts should all be considered. These may cover the impact on health of less indoor air pollution and improved sanitation; the impact on the environment locally (improving living conditions in the immediate vicinity), nationally (forest conservation) and globally (reduced greenhouse gas emissions). They may also include increased agricultural outputs due to improved soil conditions, and the alleviation of poverty through access to alternative cooking and lighting solutions. However, since many of these benefits cannot yet be quantified, the World Bank report (2008 – see Box 2) focused on environmental and agricultural benefits. Based on assumptions given in the report, the economic rates of return (ERR) of the Eco-Farming Project (which centred on promoting domestic biogas) were estimated at 22–30 per cent in different provinces. The largest economic benefits stem from reduced energy costs (36 per cent), saved labour time (34 per cent), and lower greenhouse gas emissions (18 per cent) (World Bank, 2008).

Another case study in Enshi Prefecture of Hubei Province estimated that the annual environmental benefits of a typical domestic biogas digester is about CNY 1706, of which 61.2 per cent was the reduction of deforestation due to savings of firewood, 17.3 per cent the disposal of animal waste, 14.1 per cent using bio-slurry as fertilisers, and 6.8 per cent the reduction of greenhouse gas emissions (Zhang, 2008). However, the estimate does not seem to be based on sound assumptions. The study takes the cost of manure disposal to be the same as it would be to treat animal or human waste in an urban context, and then adds the value of bio-slurry as a fertiliser. This amounts to double-counting the two benefits (animal waste disposal cost, and bio-slurry fertiliser value). In fact, in the absence of a biogas digester, manure would probably be used directly as a farm fertiliser anyway.

The direct value of biogas as a cooking fuel can be calculated by substituting the value of alternative fuels (LPG, coal, or firewood) where biogas is used for cooking and water heating only. The calculation results may change dramatically depending on the fuel and its market price. LPG provides a useful reference to

Box 2.
Does domestic biogas pay?

The most comprehensive economic and financial analysis of domestic biogas programmes in China to date is probably a report by the World Bank's China Eco-Farming Project, based on data obtained in September 2006 (World Bank, 2008). For a financial analysis, the report calculated the benefits of a normal-sized domestic biogas digester as follows:

1) Reduced use of traditional fuels (firewood, agricultural waste such as rice husks or corn cobs, coal, petroleum gas, and electricity) at about 1.33 tonnes of coal equivalent fuel per year per household.
2) Saved labour time at 21 working days a year, of which 30 per cent would be used for income-generating activities at CNY 20 per working day. This is achieved through changes to time spent on firewood collection, cooking, cleaning animal sheds, bio-slurry and fertiliser application, and maintaining biogas equipment.
3) Offsetting chemical fertilisers with bio-slurry at 4.2 tonnes of solid residue and 8.4 tonnes of liquid bio-slurry, assuming:
    a. construction and installation cost at CNY 3165;
    b. annual minor maintenance costs at CNY 100 and regular major maintenance costs at CNY 500 every five years;
    c. upfront investment from the household at CNY 2400 at the interest rate of 6 per cent; and
    d. lifespan of the biogas digester at 20 years and discount rate at 12 per cent.

A calculation based on all the factors above finds that the net present value (NPV) of a normal biogas digester is about CNY 1240.

It is, however, unlikely that most households would reap all of these benefits. If the saved labour time would not generate income and the bio-slurry is used to substitute animal manure rather than chemical fertilisers, then the NPV becomes minus CNY 295, making investment in biogas digesters financially unattractive.

find biogas's 'value', being a similar cooking fuel. If biogas is used as a substitute for solid biomass fuel (such as firewood) or coal, the real savings would be much lower (see below). Similarly, the direct value of bio-slurry may be calculated by substituting the value of chemical fertilisers. However, bio-slurry's major added value over manure as a fertiliser is its reduced health risks (since pathogens are killed in the digester). Many costs and benefits studies fail to recognise this and tend to attribute any associated income, such as profits from cattle raising or vegetable growing, as benefits of biogas digesters, which overestimates its real benefits.

From a macro-economic perspective, it also makes good sense to analyse indirect energy inputs and the release of environmental pollutants or greenhouse gas emissions during the production and transportation of biogas construction materials and biogas appliances. For example, cement production involves commercial energy consumption in the form of coal, oil, gas, and electricity. At the cement industry's current levels of energy consumption, producing one tonne of cement consumes about 100kg of coal equivalent and releases about 1000kg of carbon dioxide. These factors should be considered in any impact analysis of biogas programmes, particularly when calculating emission reductions from a Clean Development Mechanism (CDM) perspective (see Section 4.1 below).

2.3 Key parameters

The key parameters for the calculation of costs and benefits of a domestic biogas digester include: 1) the amount of labour days spent on biogas digester operation and the cost of labour; 2) the reference price of biogas as a cooking fuel; 3) the actual amount of biogas produced and used in a year; 4) the price difference between biogas feedstock and the discharged bio-slurry; and 5) the number of days in a year when biogas digesters are in normal use. The results of a financial assessment can be very sensitive to some of these parameters, which may significantly change the value for costs and benefits. Due to the key parameters' wide range of variation, it may not be possible to generalise about the financial viability of domestic biogas digesters across the country.

Biogas user households are far more concerned with direct than indirect costs and benefits when deciding whether or not to invest in a digester. The yearly biogas production of an eight cubic metre digester in normal use is estimated at 300m^3 in northern China with its long winter and 500m^3 in southern China with year-round favourable temperatures, with an average of roughly 385m^3 across the country[9] (Hao & Shen, 2006), though the actual amount used by the household may be lower.[10] If biogas used for cooking is taken as a substitute for LPG, then the reference price of biogas would be around CNY 3.0 per cubic meter.[11] This makes the direct output value of a biogas digester at CNY 900–1500 a year depending on actual biogas production. If the installation costs are set at CNY 3000 and the labour inputs set at 20 labour days a year for regular feeding and discharge to ensure adequate maintenance, then in northern China (with an annual biogas production of 300m^3), the investment in a biogas digester would not be recovered in five years unless labour costs less than CNY 15 per labour day, or in 10 years for labour costs at CNY 30 a day. Similarly, in southern China the investment would not be recovered in five years if labour costs are more than CNY 45 a day, or in 10 years if labour costs more than CNY 60 a day (with an annual biogas production of 500m^3), even without counting the cost of occasional repairs and gas appliance replacements. A rough statistical analysis shows that only if the labour costs are less than CNY 30 and CNY 60 a day in north and south China respectively may the investment in a biogas digester be recovered over its 20-year lifespan. This is assuming that the government subsidy is CNY 2000 for each biogas digester and average repair and replacement costs are CNY 50 each year. So, labour costs can be one of the most important factors in the costs and benefits analysis of domestic biogas digesters. In other words, the direct benefits of a domestic biogas digester may not necessarily exceed the costs over the expected lifecycle, if biogas is used exclusively as a substitute for LPG for cooking.

From the government's point of view, both direct and indirect economic benefits are critical to the cost-effectiveness evaluation, and for justifying investment in the national biogas programme. However, it is likely to be the direct financial return of a biogas digester that most affects individual households' decisions on whether or not to invest in it.

9 Daily biogas production rates are usually between 0.15–0.30m^3 (digester volume) in normal temperatures (10–30°C) with adequate feedstock. An eight cubic metre biogas digester may produce less than 1.0 cubic metre of biogas in the cold season and more than 2.0 cubic metres in the hot season. At the current cooking energy consumption level of around 1.5 cubic metres a day in rural households, this may be more or less than the needs a rural households on a daily basis due to seasonal variation in biogas production.

10 The use-based biogas subsidy pilot project in central China's Hubei Province adopts the following definitions to evaluate domestic biogas digesters: 'good' for those providing 300m^3+ of biogas over 12 months; 'average' for those within 200–300m^3 a year; and 'poor' for those below 200m^3 a year, based on the actual measurement results of gas flow meters.

11 The 'reference price' of biogas was calculated assuming an LPG market price of about CNY 7.0/kg and 1m^3 of biogas having roughly equivalent energy to 0.42kg of LPG.

3
Financing and biogas digester systems

3.1 Sources of funding

Investment in China's domestic biogas programme involves a variety of players in both public and private sectors. Major sources of funding come from the national government with matched or additional funding from local government at provincial and county levels. From 2003 to 2012, the cumulative investment in the biogas sector from the national government alone reached CNY 31.5 billion (USD 4.5 billion), sourced through treasury bonds. This investment pulled in CNY 13.9 billion from local governments and CNY 46.4 billion from rural households (MoA, 2013). Of the total investment of the national government in the biogas sector, about two thirds were used to directly subsidise rural households for biogas construction (Wang, Tu, & Chen, 2012).

In addition to the government budget allocated to rural biogas construction in the agricultural sector, other government agencies help to fund domestic biogas development on a project-by-project basis, including forestry conservation, public health, poverty alleviation, environmental protection, and ethnic minorities development agencies. For example, the annual investment on biogas projects in Sichuan Province alone reached a historic high of CNY 2 billion (USD 293 million), of which CNY 1.7 billion were used for domestic biogas construction. The main funding sources included: 1) treasury bonds for rural biogas projects from central government; 2) special biogas funding as part of government financial incentive packages, aimed at expanding domestic demand to tackle the international financial crisis; 3) rural biogas project funding from the Grain for Green Programme, a government forestry conservation initiative; 4) medium and large biogas project funding for livestock farms; 5) funding from central government ring-fenced for post-earthquake reconstruction; and 6) funding from the provincial government for poverty alleviation and rural development (Van Nes & Xia, 2010).

Multilateral and bilateral development organisations also played an important role in supporting biogas development in China. For example, the World Bank provided a USD 120 million loan in 2008 to the Chinese government's Eco-Farming Project, for rural biogas construction in five provinces (Anhui, Chongqing, Hubei, Hunan, and Guangxi). The Asian Development Bank (ADB) provided a loan of USD 33.1 million to China in 2003 for household biogas development in four provinces (Shanxi, Henan, Hubei and Jiangxi), and another USD 66.08 million in 2010 to improve the performance of the biogas sector through demonstrations in four provinces (Heilongjiang, Henan, Jiangxi, and Shandong). The German development agency GIZ also provided an additional grant of USD 4.6 million in cooperation with the ADB funded project. In 2009, the French Development Agency provided a USD 50 million loan to China for the rehabilitation or reconstruction of rural biogas digesters in the earthquake-affected areas of Sichuan Province. This reconstruction project also acquired a loan of USD 28.97 million plus a grant of USD 1.5 million from the International Fund for Agricultural Development (Chen, 2011).

Private companies are also actively involved in the biogas sector, by investing in biogas appliance manufacture and the mass production of commercial digesters. The aggregated annual production capacity of biogas cookers from more than 100 companies across China has now reached 10 million sets (Li & Xue, 2010). One company in Sichuan Province invested about CNY 300 million in fibreglass digester production facilities (Hongqi, 2011).

Some international non-profit, non-governmental organisations (NGOs) are also involved in China's rural biogas projects with funding from various sources, including public and private foundations, contributions from corporate social responsibility programmes, and donations from their individual members. These NGOs include Nature Conservancy, Oxfam, World Vision, and Worldwide Fund for Nature (WWF).

Carbon financing under the Clean Development Mechanism (CDM) has also emerged as a source of funding to domestic biogas projects. Around 33,000 household biogas digesters in eight counties of Enshi Prefecture, Hubei Province, were bundled together for carbon financing with the anticipated annual income of USD 0.82 million over 10 years, of which 60 per cent would be allocated to biogas households, 18 per cent for technical services, and 22 per cent for monitoring and project management (MoA, 2009). The first half-yearly revenue from this CDM scheme was disbursed to the beneficiary households in August 2011. Between 2011 and 2012, 38 household biogas CDM projects from eight Chinese provinces (Guangxi, Guizhou, Hebei, Henan, Hubei, Hunan, Liaoning, and Sichuan) were registered (NDRC, 2013).

In most cases, the beneficiary households contribute a significant portion of the installation costs of biogas digesters, and all the operational costs, in the form of cash and labour. Reports from different sources indicate that the actual contributions from beneficiary households vary widely, from labour inputs alone to between 50 and 70 per cent of the total installation cost (MoA, 2007a). If a village is not yet covered by the biogas construction plan under the national biogas programme, then households within the village may not be able to access government subsidies. In this case, they either have to wait until the village's application is included in the government plan or pay the full cost of construction. The Treasury Bonds For Rural Biogas Construction Programme states that to be eligible for biogas construction, villages must meet certain requirements; for instance 70 per cent of village households must own an adequate number of livestock (the minimum is the equivalent of three pigs) and be able to share the cost of biogas construction (MoA, 2003). These requirements inevitably prevent some households from accessing government subsidies for biogas projects.

3.2 Financial instruments and mechanisms

The financial instruments of government investment in rural biogas projects are primarily subsidies in the forms of cash grants to households and the provision of construction materials, biogas appliances, and technician services. Other financial instruments like loans or guarantees are rarely used except for medium and large-scale biogas plants.

The amount of subsidy from the national government for domestic biogas digesters increased from CNY 800–1200 per unit in 2003 to CNY 1300–3500 (USD 200–535) in 2011, depending on project location.[12] This subsidy contributed roughly two-thirds of the installation costs for a simple biogas digester (CNY 2300–

12 Current subsidies for domestic biogas from the national government is CNY 1300 (USD 210) per digester in the eastern region, CNY 1600 in the central region, CNY 2000 in the western region (including three provinces in northeast China), CNY 3500 in Tibet Autonomous Region and CNY 3000 in Tibetan-inhabited areas in other provinces and the three prefectures in southern Xinjiang (Source: MoA, 2011).

3900 or USD 365–525) or about one-third of the total costs for an advanced biogas-toilet-pigsty-kitchen upgrading project (see Section 4.3 for more detail). Matched funding from local governments may be used as project operational expenses or, in some cases, to top up national government subsidies.

The Treasury Bonds For Rural Biogas Construction Programme budget is jointly administered by the Ministry of Agriculture and the National Development and Reform Commission. On approval by the Ministry of Finance, the funding is distributed to the Department of Finance at provincial level and then down to the Bureau of Finance at county level. All funding, whether from national government or matched by local government, is transferred into a special bank account set aside for biogas construction.

Rural Energy Offices at different levels are responsible for project implementation and management within their respective administrative areas. The rural energy offices at county level are legally responsible for the whole biogas project process. This may include the collection of household applications for biogas construction from targeted townships and villages; project planning and preliminary feasibility studies; preparation and submission of funding proposals; agreements with township governments and village committees; contracting with biogas construction companies; supervising construction quality; managing biogas household files; funding management; arranging post-installation services; and project reporting. While this arrangement looks systematic and comprehensive on paper, in practice rural energy offices can have various limitations in terms of staffing levels, operational funding, and advanced project management skills, with a significant effect on their capacity to fulfil all the project operations outlined above.

The purchase of biogas cookers and fittings is centrally administered by national government via an open bidding process. Provincial rural energy offices may manage bulk purchases from bid-winning enterprises for biogas project counties. The procurement of major construction materials and other biogas equipment are required to follow government purchasing procedures (MoF & MoA, 2007).

Subsidies or grant schemes from other funding sources vary from case to case. Many of them are used to provide partial to full coverage of biogas construction costs, or to top up government subsidies in remote places where construction costs are significantly higher, or to fund areas not covered by the national biogas programme.

The construction and installation of biogas digesters are always contracted to biogas service companies or individuals who are certified biogas production workers with the appropriate qualifications, tools and equipment.[13] Beneficiary households provide any labour and cash needed to fill financial gaps left by the government subsidy.

3.3 Biogas systems

To ensure easier routine management of a biogas digester, and to create synergies from the multiple benefits of biogas technology, domestic biogas digesters in rural areas are usually designed with 'upstream' and 'downstream' connections. The 'upstream' connections carry feedstock into the biogas digester, such as from a toilet, livestock pen, or water storage (in arid areas). The 'downstream' connections carry biogas and bio-slurry to where they can be used, such as a kitchen, vegetable plot, mushroom cultivation area, orchard, or fish pond. This has led to a variety of biogas systems and created biogas jargon in Chinese such as 'three-combined', 'one-plus-three', 'three-in-one', 'four-in-one', and 'five-in-

13 There is a national standard for quality checking and acceptance for domestic biogas digesters, coded GB/T4751-2002.

one'. A brief definition of these terms will help to explain biogas systems in rural China.

The three-combined biogas model

Traditionally in rural China a domestic biogas digester is integrated with the toilet and livestock pen ('three-combined') allowing animal and human waste to be fed in easily. This arrangement helps ensure that enough feedstock is added to the digester on a regular basis, in order to produce sufficient biogas for household cooking and to destroy pathogens from human and livestock waste through the anaerobic fermentation process. This approach has been used in China since the 1950s.

The one-plus-three renovation

This model is also known as a 'rural biogas digester and three renovations', since a rural household renovates or rebuilds the livestock pen, toilet and kitchen as well as constructing the biogas digester. These renovations are expected to significantly upgrade a rural household. The renovations are also a requirement for rural biogas construction under the Treasury Bonds For Rural Biogas Construction Programme.

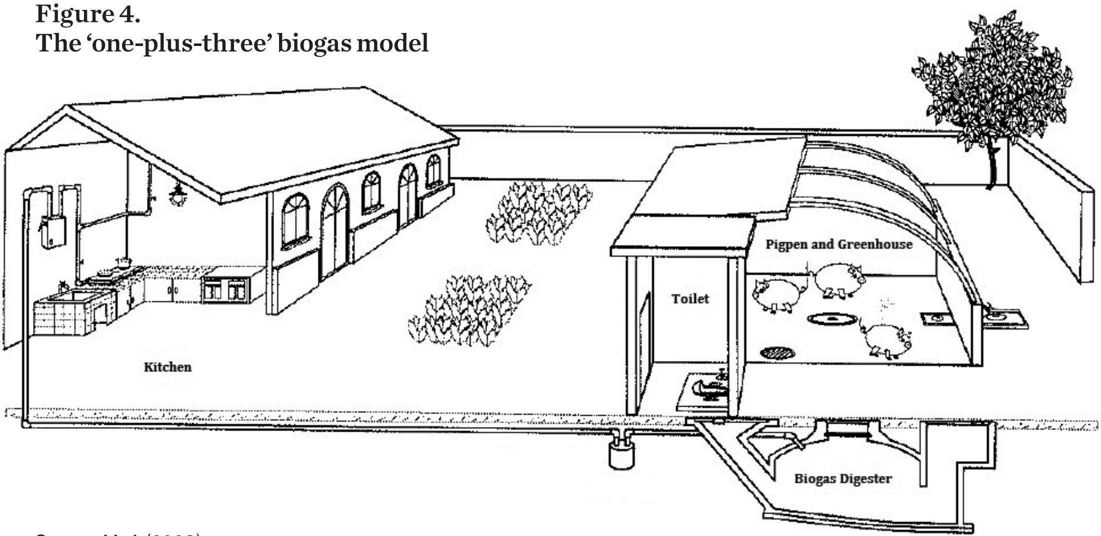
In addition to connecting an animal pen and toilet with the biogas digester as prescribed in the three-combined model, a kitchen renovation is included. Specific details for this model are available in the Agricultural Industry Standard NY/T1639-2008 Technology Criterion on Rural Biogas Digester and Three Renovations (MoA, 2008). A diagram of the recommended layout is shown in Figure 4.

However, the additional costs of the three supplementary renovations can be much higher than that of a simple biogas digester – from a quarter to twice as much – in different regions, depending on pre-renovation conditions. Some field studies indicate that the actual rate of 'three renovations' varies from site to site, from almost 100 per cent of households completing all three renovations, to less than 30 per cent.

The three-in-one model in southern China

The official name of this model is 'household-scaled biogas and integrated farming system -

Figure 4.
The 'one-plus-three' biogas model



Source: MoA (2008)

southern model'. The 'three-in-one' model differs from the three-combined digester model, which prioritises the collection of feedstock, in that it emphasises the comprehensive use of bio-slurry.

Originally, the three-in-one name referred to 'pig-biogas-fruit', using pig manure for biogas production and then bio-slurry as fertiliser for orange trees. Following the success of this model, which saw an improvement in both quality and quantity of fruit through the use of bio-slurry – generating more income for households – the model was well disseminated in southern China from the 1980s. It gradually diversified into other applications such as 'pig-biogas-vegetables', 'pig-biogas-fish', 'pig-biogas-rice', and 'cattle-biogas-mushrooms'. In 2001, the Ministry of Agriculture issued industry specifications on the design, construction and use of this model (NY/T 465-2001).

The core value of these three-in-one models is that they 'extend the value chain' of biogas technology (each part of the process adding value to the final product) and create opportunities to generate income through the application of bio-slurry.

The four-in-one model in northern China

In a 'four-in-one' model setting, a biogas digester, a cattle pen, and a toilet are all installed inside a greenhouse, which is also used for vegetable or fruit production. The most significant advantage of such a design is that the higher temperature in a greenhouse enhances biogas production, animal growth, and

Figure 5.
The four-in-one biogas model

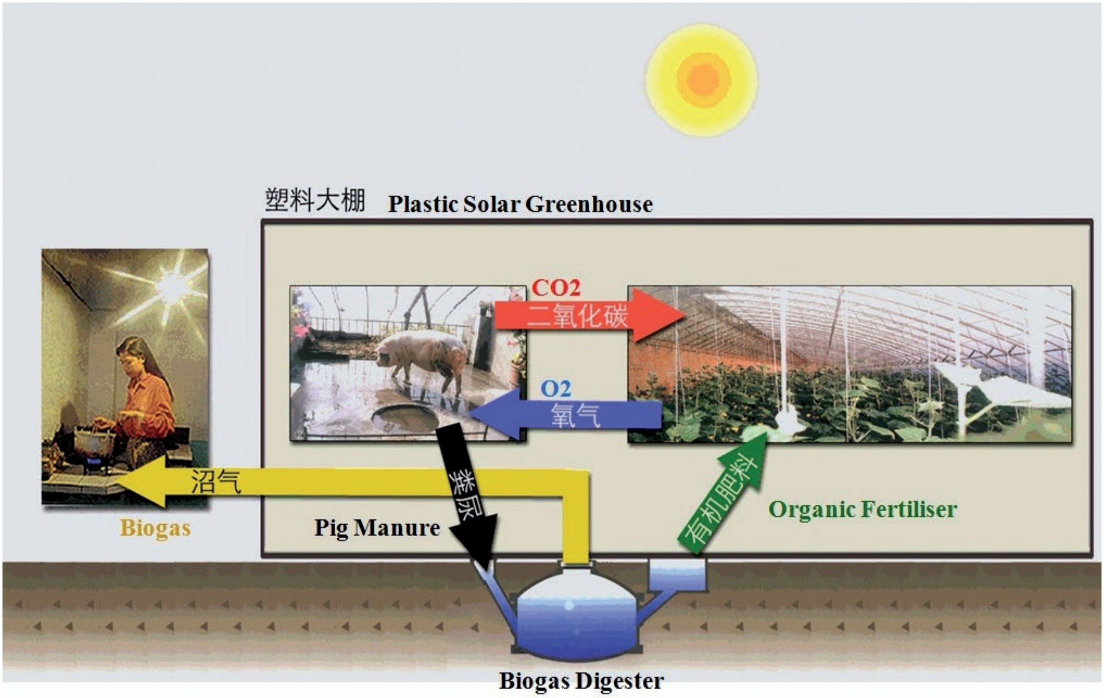


Image courtesy of Hao, X./MoA, China

vegetable production. This is particularly beneficial during the cold season in northern China or other high altitude areas. Technical specifications of this model can be found in 'Household-Scaled Biogas & Integrated Farming System – Northern Model' (NY/T 466-2001).

Not only does this system extend the value chain of biogas technology, but also lengthens both the growing season and biogas production season by raising the temperature. The use of bio-slurry is much easier and more efficient inside a greenhouse, helping to add value to fruit and vegetables. Biogas may also be burned in gas lamps to help heat the greenhouse, to supplement daylight hours, and to enhance carbon dioxide concentration within the greenhouse to improve vegetable growth. Figure 5 shows the components of the four-in-one system. This model was disseminated on a large scale in northern China, particularly in Liaoning Province in northeast China.

Unlike the three-in-one model in southern China, the four-in-one system adds the major component of a greenhouse, which may require three to 10 times more investment than a normal biogas digester, or even more depending on the size of the greenhouse (usually 200 to 400m^2). Though the output value of such a system is very good, it is more capital intensive in construction and labour intensive in operation.

The five-in-one model in northwest China

The 'five-in-one' model was designed for the arid areas of northwest China, where water shortages and long cold winters restrict agricultural production and the operation of biogas digesters. Unlike the four-in-one model, the greenhouse above the biogas digester is not used for growing vegetables, but instead as a chicken house and pen for livestock. Another addition to the system is a rainwater collection cellar with a capacity of 40 to 60m^3, designed to meet the water needs of the household and to support biogas production. The liquid part of the bio-slurry may be sprayed as foliar fertiliser or mixed with collected rainwater to irrigate the

Figure 6.
The five-in-one biogas model

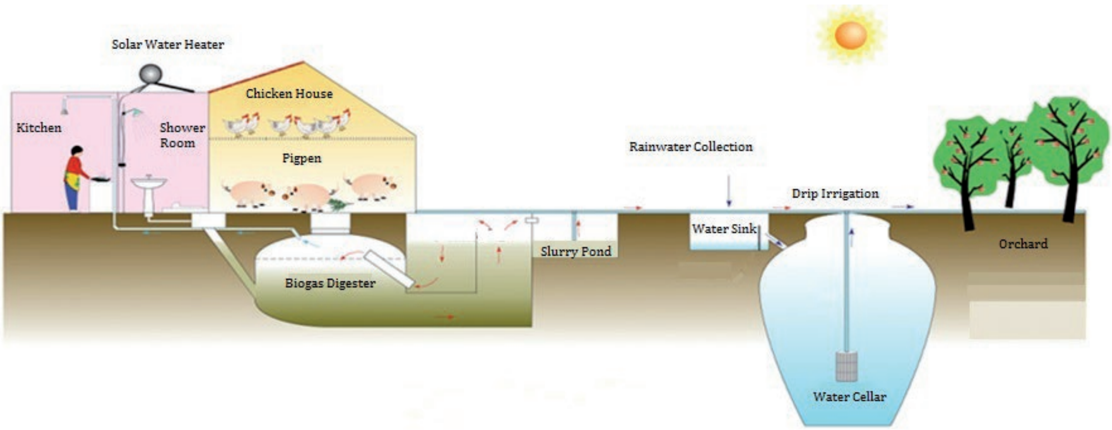


Image courtesy of Northwest A&F University, China orchard. The costs of this system are very much dictated by the water cellar component. This design is very appealing to local people as it greatly eases the pressure on water resources and supply.

Each of these biogas construction models has its comparative advantages and limitations, making each one more suitable to some circumstances than others. However, their common feature is using biogas technology as the key component linking animal production, plant cultivation, biogas production, and environmental protection. The more comprehensive models help extend the value chains and realise better economic benefits; but these have higher capital costs and are therefore of limited value to those on lower incomes. Due to the limited value of biogas as a cooking fuel compared to a fuel such as LPG, ways should be explored of adding value to biogas and bio-slurry use to improve the economic performance of biogas technology in rural areas.

In addition to these typical household-scale biogas production models, other models exist which are beyond the scope of this study to look at in detail. They include joint-household biogas production; community-scale biogas plants for centralised biogas production and distribution; and biogas construction integrated with post-installation biogas services.

3.4 Services to biogas user households

Inadequate biogas service systems and insufficient post-installation services have emerged as a major obstacle to the normal functioning of domestic digesters. In response to this, the national biogas programme has started to shift its emphasis – from aiming to rapidly scale up domestic biogas digesters to cover more households, to achieving more balance between expanding in scale and ensuring normal functioning of the existing installations.

In 2007, the government launched the National Rural Biogas Service System Development Initiative, aiming at nurturing sustainable and market-driven services to rural biogas users. This initiative provides grants for the establishment of biogas service outlets at village and township levels. Grant funding is open for applications from individuals, companies, institutions, associations or biogas cooperatives. Grant size was initially set at CNY 8000 per service outlet in the eastern region, CNY 15,000 in the central region, and CNY 19,000 in the western region (MoA, 2007b). Since 2009, it has been adjusted to CNY 25,000 for eastern and central regions, and CNY 45,000 for western regions. The grants are usually provided in the form of hardware, such as tools, equipment, and bio-slurry discharging vehicles, which are owned by local township governments or village committees and leased to service providers under contract or agreement. Each service outlet is expected to serve 300 to 500 biogas households. Specific services may cover troubleshooting, bio-slurry discharging and delivery, feedstock supply and digester feeding, and bio-slurry storage based on contracts between biogas users and service providers.

By the end of 2011, the government had invested CNY 2.54 billion (USD 400 million) in the development of national biogas service networks, reported to cover 75 per cent of biogas users through 90,000 village service outlets across the country (MoA, 2012d). Biogas service networks are crucial to helping ensure high functional rates of domestic biogas digesters. The challenge for service networks, at an operational level, may be financial sustainability on a purely market basis without being subsidised. There are reports from the field that low profits from such services have led to operational difficulties, causing biogas service technicians to drop out, although there are also success stories. It seems that there is still a long way to go before biogas service networks reach maturity, and their overall performance is yet to be fully evaluated.

4
Rural households' attitudes towards domestic biogas

Household-scale biogas production is commonly considered an appropriate technology for rural areas in most developing countries. It helps produce clean cooking fuels and good organic fertilisers through the effective treatment of animal and human waste or other organic waste. Yet despite all the direct and indirect benefits, adoption of this technology varies widely across regions. An analysis of rural households' attitudes towards the construction and operation of domestic biogas digesters may help to explain the problems that currently hinder sustainable development in the biogas sector.

4.1 Rural households' willingness to pay

Rural households are the directly targeted beneficiaries of China's government-led national biogas programme. As basic social and economic units, rural households have the dual characteristics of both producers and consumers. Household income is used first to meet basic needs and then to invest in other productive and non-productive activities. Whether or not a household is willing to invest cash and labour in biogas construction very much depends on its understanding of the cost-effectiveness and the comparative advantages of biogas technology versus other options. A rural household's financial calculations may not be very sophisticated, but will involve the same basic factors as any financial decision, such as an estimation of costs and benefits, profit maximisation, risk minimisation, capture of opportunities, or waiting until the conditions are right.

There are many factors that affect whether or not a rural household might choose to pay for a domestic biogas project. While it would be difficult to work out an all-inclusive list of such factors, the following are likely to have some influence:

Financial factors

1) The total cash costs of biogas digester construction and other required renovations under the national domestic biogas programme;
2) The amount of subsidy from government or other sources;
3) The disposable income level of target households;
4) The amount of labour required to construct and operate a biogas digester versus traditional tasks to provide energy (e.g. collecting firewood) and the 'opportunity'[14] costs of labour;
5) The cost of biogas feedstock if it is purchased, and the cost of disposing of household waste, if any;
6) Current expenditure for basic cooking and lighting – firewood, agricultural waste, charcoal, LPG, kerosene, candles, electricity;

14 The 'opportunity cost' is the cost of forgoing a benefit due to making one of a limited number of choices; e.g. time which could have been spent earning money is forgone by having to collect firewood.

7) The availability and market price of alternative cooking fuels with similar fuel properties, such as LPG;
8) The cost of bio-slurry discharge and use;
9) The efficacy of bio-slurry as a fertiliser compared to manure and commercial fertilisers;
10) The availability of spare parts and the cost of technical support for troubleshooting.

Technical factors

1) Livestock production practices and the availability of manure as feedstock for biogas production;
2) Suitability of the local environment for biogas production (such as temperature and availability of water) or digester construction (such as ground space availability, difficulties with ground excavation, underground water table, soil bearing capacity, or length of rainy season);
3) The annual yield of biogas and its distribution over months, or capacity to meet household cooking fuel needs on a daily basis;
4) The risk of the biogas digester or cooking appliances malfunctioning;
5) The construction quality and its effect on normal operations over the expected lifespan;
6) The degree to which a biogas digester will improve environmental hygiene, such as the risk that it will produce an unpleasant smell, or possibility that it will reduce the number of flies and mosquitoes.

Socio-economic factors

1) The expectation that cooking with biogas will be less time consuming, allowing more leisure time;
2) The potential of biogas use generating an income;
3) The reaction to failures of previous biogas projects;
4) The potential risk to life and property, such as fire, and accidents with bio-slurry discharge or digester repair due to overlooking safety instructions, as has happened occasionally in the past;
5) The influence of cultural and social taboos and preferences, for instance against using biogas generated by animal and/or human waste for cooking;
6) Household decision-making patterns and gender equality in society.

Each of these factors could be further disaggregated into sub-factors for an in-depth analysis. Rural households at different income levels may give different weight to each of these factors, but in combination they impact on decision making and the willingness of households to pay for biogas digesters.

Survey results from Hebei Province

A field survey covering 200 households from five counties in the southern part of Hebei Province reported that 54.5 per cent of the sampled households considered the performance of domestic biogas digesters as good or satisfactory, and 45.5 per cent as more or less unsatisfactory. The main concerns of dissatisfied households were reported to be the lack of technical support and services (55.8 per cent), the lack of financial capital (21.2 per cent), the lack of feedstock (19.2 per cent), and the unpleasant nature of working with bio-slurry discharge (3.9 per cent) (Wang *et al.,* 2011).

Survey results from Yunnan Province

Another field survey with 753 sample households from 13 counties of Yunnan Province in southwest China found that villagers in general recognise the advantages and benefits of biogas digesters in saving firewood, electricity, and labour, as well as in improved hygiene in the toilet, animal enclosures and kitchen. Out of the 631 households with biogas digesters between 6 and 18 cubic metres in size (mostly 8 cubic metres), over 98 per cent received subsidies from the government of CNY 200–5000 (average CNY 858); only 1.7 per cent of the biogas digesters were built wholly at the owner's cost. Cash inputs of households for biogas construction vary from CNY 100–4400 (average CNY 1233). Government subsidies account for 40.8 per cent of the total cash costs in average. Labour inputs for biogas construction vary from 4 to 80 labour days (mostly 30). Over 80 per cent of the installed biogas digesters are in regular use. Major problems with biogas digesters not in regular use include gas leakages due to poor construction of digesters or poor installation of gas pipelines; lack of timely feeding and regular discharge of bio-slurry; and gas blockages along the pipeline, or minor failures with biogas cookers. With regard to the 120 sampled households that had not yet built a biogas digester, their main reasons were: 1) the drudgery and inconvenience of feeding and discharging biogas digesters; 2) household financial difficulties; 3) lack of labour, feedstock, or ground space for biogas installation; and 4) poor cost-effectiveness due to low biogas production (Zheng, 2010).

Field study in Yunnan Province

The level of energy provided by an installation versus the complexities of operating it also has a significant effect on households' decisions. For example, The Nature Conservancy implemented a Green Village Credit project in Yunnan Province of China between 2004 and 2007. The average annual income of the local population was estimated at roughly USD 125 per capita (at 2005 exchange rates). The project supported the installation of both domestic biogas digesters and solar water heaters (SWHs). While the upfront capital investment of a SWH, at USD 70, was about four times higher than that of a biogas digester (comparing both after subsidies), most households were much more willing to invest in SWHs, which are almost maintenance-free and can generate enough hot water almost all year round for household use. In comparison, many domestic biogas digesters can only meet a household's cooking needs for six to ten months a year if well managed (CREED, 2005).

Personal observations

Based on personal observations and communications with biogas practitioners in China, it appears that rural households at middle to upper-middle income levels are the most willing to invest in biogas digesters. High-income households can afford cooking fuels and value labour inputs and leisure time more highly, so they normally prefer more advanced cooking energy options, such as LPG or electricity. Low-income households usually give higher priority to spending on basic living expenses such as food, medical care, child education, and house improvement, as well as necessities for agricultural production such as seeds, fertilisers, and pesticides. Though low-income rural households stand to benefit the most from upgrading their fuel and from using bio-slurry as fertiliser, their lack of spending power prohibits them from investing in biogas construction.

The government's readiness to invest in this technology contrasts with that of individual households – the targeted direct beneficiaries – since the government values the economic benefits, while householders focus on the direct financial benefits of domestic biogas digesters. Adequate government subsidies are therefore designed to help reduce direct costs, stimulating individual households to invest in biogas construction. However, over-subsidising or mis-targeting subsidies may also distort households' decisions, resulting in the construction of biogas digesters that are not fully used. Government policies and incentive packages must therefore carefully take into account the external costs and benefits, and target the subsidies accurately at the right groups of people. It is crucial to create an enabling environment in which householders can make the decision to invest as a free choice, as the owner and operator of the biogas digester, without being overly influenced by subsidies or other external factors. This helps to ensure a stronger sense of ownership, better dynamics of supply and demand, and more efficient use of subsidy funding.

4.2 Rural households' ability to pay

Aside from the willingness to pay, which reflects how households choose and prioritise spending, the *ability* to pay reflects households' level of disposable income. Whether or not rural households can afford biogas technology depends on income levels, current levels of spending on cooking fuels (in absolute terms and as a percentage of total income), the upfront investment and operational costs of biogas digesters, and the prices of alternative solutions.

Poverty trends in rural China

As a broad background, around half of China's population live in rural areas (according to the 2010 census), where about two thirds of the population are engaged in farming, forestry, animal husbandry and fishing. The poorest rural households tend to derive a large share of their income from agricultural activities, often with low levels of productivity and net profits. The average annual income of China's rural population reached CNY 7917 (roughly USD 1250) in 2012. However, there are significant disparities across regions and between the rich and the poor within regions.

According to the latest national poverty line, set at an annual income of CNY 2300 per capita (roughly USD 1 a day), there were still around 100 million people or about one tenth of China's total population living in poverty by the end of 2012 (OPAD, 2013). Most of the poor population live in the central and western parts of the country, especially in border regions, areas inhabited by ethnic minority groups, and those in remote, mountainous locations. The poverty and inequity trends in China are shown in Figure 7, based on World Bank studies. Table 1 gives a profile of income and expenditure of rural households in different regions of China.

Income and consumption expenditure of rural households

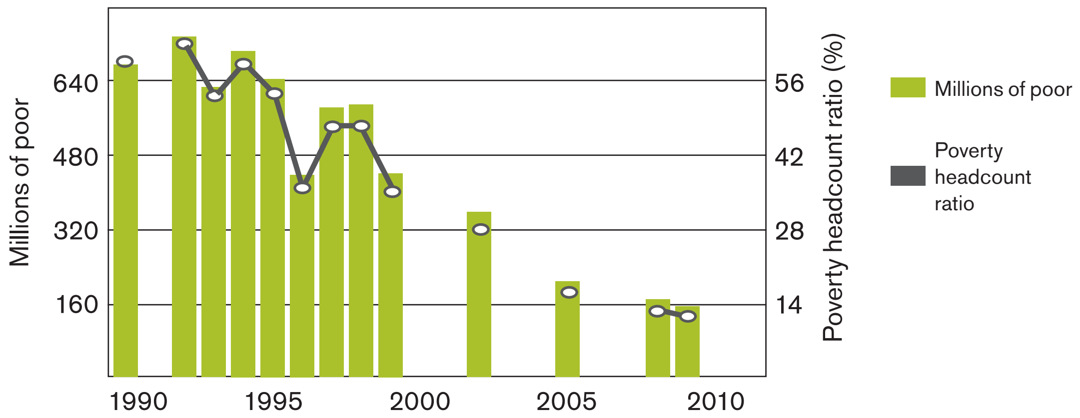
Rural households' expenditure on energy is not singled out in the official statistics, but comes under the 'Household facilities and articles' category, which accounts for 4.4–7.4 per cent of rural households' total cash expenditure, or CNY 738–1484 annually per household averaged across regions (NBS, 2012b). Compared to average rural households' annual cash expenditure of CNY 14,870–24,084 or annual savings of CNY 7079–11,214, the construction cost of a domestic biogas digester at CNY 2250–4850 seems fairly affordable.

Disparities in rural income across regions

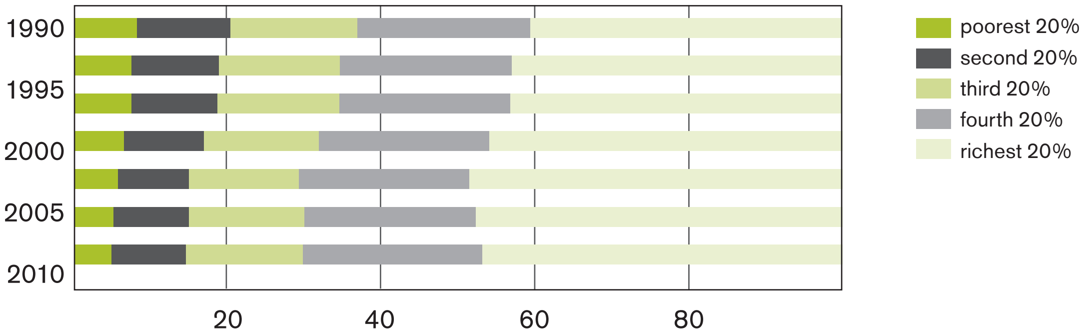
The financial situation of low-income rural households, however, can be very different from the average figures, when considering regional differences and disparities between the rich and the poor. For example, the annual per capita net income in rural Gansu and Guizhou provinces in western China only corresponds to roughly one third to one quarter of that in Shanghai and Zhejiang province in eastern China (NBS, 2012c). On average, the annual net income of poor rural households corresponds to 36.8 per cent of middle-income rural households, or 16.6 per cent of high-income rural households. The annual cash income of rural households in the poor and the lower-middle quintiles are CNY 15,706 and CNY 21,486 respectively, while their annual cash expenditure is CNY 23,904 and CNY 23,509 respectively, the shortfall in income being covered by loans. This makes an annual deficit of CNY 8198 for the poor households and CNY 2023 for the lower-middle income households. Significant household expenditure, for example house building and major medical treatment, can put low-income rural households in debt for many years. In comparison, rural households in the

Figure 7.
Poverty and inequity trends in China

People living on less than USD 1.25 a day



Distribution of income by quintile



Source: World Bank (2013)

middle and the upper-middle quintiles have an annual surplus of CNY 1293 and CNY 5503, respectively (NBS, 2012a).

Based on these figures, the construction cost of a domestic biogas digester at CNY 2250–4850 would be a significant investment for rural households below the middle income level. Even after government subsidies at CNY 1600 for the central region and CNY 2000 for the western region, it may well still not be affordable.

Almost all financial institutions running on a commercial basis, however, consider domestic biogas projects as non-productive and therefore are not prepared to develop loan products to finance biogas construction. Rural households with low income levels already face difficulties in accessing loans, let alone loans for biogas construction.[15] So, the ability to pay for biogas installation is another major challenge in many cases, even if there is willing to pay for it.

15 There are hardly any reports of loans for household biogas; these are mostly for medium or large-scale biogas plants.

Table 1.
Income and consumption expenditure of rural households in China (2011)

	EASTERN	CENTRAL	WESTERN	NORTHEASTERN
Annual net cash income (CNY)	35,298	25,909	21,949	26,013
Wages and salary	52.3%	43.0%	34.5%	25.9%
Household operations	35.9%	48.8%	53.0%	59.9%
Others (properties and transfers)	11.7%	8.2%	12.5%	14.1%
Annual cash expenditure on consumption (CNY)	24,084	16,932	14,870	16,709
Food	36.4%	34.3%	33.1%	35.1%
Clothing	6.7%	7.1%	7.6%	8.9%
Residence	18.7%	21.0%	20.9%	16.0%
Household facilities and articles	6.2%	7.4%	6.9%	4.4%
Transport and communications	12.3%	10.1%	11.9%	11.5%
Education, culture and recreation	8.9%	8.0%	7.6%	9.8%
Health care and medical services	8.3%	9.4%	9.8%	11.5%
Others	2.6%	2.8%	2.3%	2.9%
Average household size (number of people)	3.68	3.97	4.18	3.34

Source: NBS (2012b)

5
Reflections and lessons learned

5.1 Tackling current problems

The development of domestic biogas in rural China has reached a remarkable scale, covering around a quarter of rural households and benefitting up to 100 million people. However, a variety of emerging problems have brought major challenges to the robust development of domestic biogas in rural China. At present, concerns centre on the normal utilisation rate, and routine operations and maintenance of domestic biogas digesters.

Normal utilisation rate

As for the proportion of digesters in normal use, field studies from different sources or geographical regions report widely varied figures, from less than 30 per cent to over 90 per cent. While most of the reports did not explicitly define the term 'normal utilisation rate', these results could still reflect the fact that a significant number of domestic biogas digesters are not functioning well in some areas for parts of the year, at least from the perspective of biogas user households.

Technically, a domestic biogas digester six to ten cubic metres in size operating in normal temperatures may not necessarily be able to produce enough biogas to meet the household's needs for cooking fuel all year round. This is particular true in areas with seasons cold enough for the bio-slurry to fall below 10°C. In low temperatures, the fermentation process slows down and may even stop, however sufficient the feedstock and the management of the biogas digester. For a realistic assessment, only the days in a year when the ground surface temperature is high enough for biogas fermentation should be counted as functional days. The length of such periods varies from 8 to 12 months in the tropical and sub-tropical climate zones, and between 4 and 8 months in warm and intermediate temperate zones and some parts of the plateau climate zones, and less than 4 months in the cool temperate zone and some parts of the plateau climate zone.

With this in mind, it is important to have a clear definition of 'normal utilisation rate' for biogas digesters, to make sure that results from different sources are compatible. In 2011 the Ministry of Agriculture classed biogas digesters as 'in normal use' if they were used for eight months a year in the southern region, or six months a year in the northern region or high elevation areas. The 'normal utilisation rate' is calculated as the percentage of biogas digesters 'in normal use' of the total samples in the area studied (MoA, 2011). This is a step towards a clearer definition. However, there are still ambiguities, as it does not include factors like the *actual* daily biogas production versus the *potential* daily production of a biogas digester during the 'in use' months. For individual households, it might be more relevant to measure the normal utilisation rate as the number of days a year a digester produces close to its full potential amount of biogas. It would also be relevant to record what proportion of the daily and annual cooking fuel needs are met by the biogas produced.

Construction quality and operational management are also factors influencing biogas production and therefore how much a biogas digester is used. Poor construction quality may lead to biogas leakage, reducing the amount of biogas available for use. Inadequate feeding and discharging of the digester would also result in a lower rate of biogas production. Therefore the quality of technical services, the availability of biogas feedstock, and the labour and time spent on operations all affect a biogas digester's performance and its rate of use.

Operation and maintenance

A popular saying about domestic biogas digesters is that their successful functioning depends 30 per cent on construction quality and 70 per cent on routine management. Though this saying is occasionally used by construction companies to excuse poor installation quality, it is generally true and reflects the importance of routine operating and regular maintenance, which generally consist of adequate feeding, regular discharging, and timely trouble-shooting.

Generally speaking, operating and maintaining domestic biogas digesters is not overly complicated and the technology fits best into the cooking fuel consumption patterns of a rural context (where consumption tends to be less than in urban households) and the need to process animal and human waste into organic fertilisers for agriculture. The current difficulties with biogas digester operation and maintenance are primarily due to changed circumstances, such as labour being less available, labour costs increasing, and animal waste also becoming less available due to urbanisation and changing practices in farming. These changes naturally cause difficulties in operating domestic biogas digesters.

If it reaches a point where neither labour nor feedstock can be taken for granted, operating domestic biogas digesters would be a problem. Alternative solutions may help to tackle this, such as using social biogas services for all or part of digesters' operation, maintenance and trouble-shooting. But adequate market competitiveness is crucial to make social biogas services a viable business, depending on the specific circumstances. The initial establishment of national rural biogas service networks is a starting point to tackle these problems. Some service delivery models have been developed, but longer-term trials of such models are required to evaluate their effectiveness and sustainability.

The total number of domestic biogas digesters in China has tripled since 2003 with an accumulative government investment of CNY 31.5 billion (USD 4.5 billion). By anyone's standards, the national rural biogas programme is huge and moving forward with impressive momentum. However, a thorough and comprehensive evaluation of its performance seems not to be available yet. After ten years of rapid development, now is high time to carefully review the problems which have emerged, in order to understand their root causes and to adjust strategies in response to rapidly changing circumstances.

Significant data gaps exist, particularly sound data on direct and indirect inputs and outputs, and quantified costs and benefits in financial and economic terms. Data monitoring and collection can be challenging, costly and time-consuming, but is likely to be worthwhile. A 'business as usual' approach may not be the least costly solution or the best way to minimise the risks associated with such a large investment.

It is worth noting that many of the problems in the biogas sector were reported by people who are not directly employed by it, or who were only engaged in the sector on a temporary basis. This may not mean that experienced biogas practitioners are unaware of these problems, but could reflect their misgivings about reporting problems, as well as a potential conflict of interest. Political will is therefore needed to encourage an objective, unbiased analysis of the sector. If possible, independent third parties should carry out this work in close cooperation with relevant stakeholders.

5.2 Improving the cost-effectiveness of subsidies

Since the government holds the overall social and economic benefits of domestic biogas digesters to outweigh the direct financial benefits to individual households, it considers the subsidies to this sector to be justified. However, there are concerns about the cost-effectiveness of the current subsidy schemes.

Installation-based versus performance-based subsidies

Currently, subsidies are allocated based on the approved number of biogas digesters to be installed. County-level rural energy offices collect household applications and submit funding proposals for approval. Once approved, the subsidy funding is allocated. Whether or not an installed biogas digester works well does not affect the payment of a subsidy as long as the construction and installation have passed their quality checks. This makes biogas digesters eligible for government subsidies, even if running far below their full potential, or if they stop being used soon after installation. In some cases, digesters had not been constructed even a couple of years after government subsidies were allocated, leaving the funding unclaimed (MoA, 2012a). On the other hand, some households may have to wait until their villages are covered by the national biogas programme. The anticipation of government subsidies may disincentivise some households from investing in biogas construction wholly at their own expense.

One solution to avoid this situation could be output-based or performance-based subsidies, which link payment of subsidies to the delivery of the installation and the performance of the installed biogas digesters. Under this scheme, service delivery could be contracted to biogas companies, which would pre-finance the project from their own capital or concessionary loans. Only after the service has been satisfactorily delivered and verified can companies be reimbursed by the government. In such schemes, the service providers make the initial investment and bear the risk of loss, rather than the government. The eligible households can also choose between several construction providers. As opposed to traditional subsidy schemes that usually focus on the upfront investment, the performance-based subsidy emphasises the outputs or the results. This approach helps provide incentives for innovation in project delivery and mobilises expertise and finance from the private sector.

Some previous projects that adopted output-based approaches have identified key factors to make this a success. These include a sound regulatory environment, reliable and motivated service providers, close links between the payment of subsidies and the outputs, recovery of operational and maintenance costs, and availability of funds to pre-finance the service delivery. How appropriate such a scheme would be for domestic biogas projects would depend on administrative costs and market maturity. This idea should be worth exploring with pilot projects.

Subsidising biogas installation versus biogas use

To improve the normal use of biogas digesters, use-based subsidies or rewards have been piloted in some areas. Under this scheme, the government provides various cash subsidies as rewards to biogas user households if the actual amount of biogas used within a year reaches certain levels. For example, households may get a reward of CNY 200–260 if their annual biogas consumption is measured at over 300 cubic meters (classed as ‘good’); CNY 150–200 for those consuming 200–300 cubic meters (classed as ‘average’); while households using less than 200 cubic meters biogas a year are considered ‘dissatisfactory’ and are not eligible for a reward. It was reported that this type of scheme improved the normal utilisation rates of biogas digesters by 10 per cent, and it motivated rural households to take better care of biogas digesters or be more willing to pay for biogas services.

This pilot project may reflect a change of mindset to focus more on the performance of biogas digesters than their installation. However, since the installation of the biogas digesters had already been subsided, and these extra rewards to encourage performance incur further, recurring subsidies, its cost-effectiveness and replication potential may need careful evaluation. If subsidising the construction of a biogas digester is thought of as a 'pushing force', then rewarding biogas use might be regarded as a 'pulling force'. If both efforts are necessary to drive forward the biogas project, that amounts to a considerable challenge. Obviously, a biogas digester is not a silver bullet or a 'once and for all' solution. The direct financial benefits are not favourable for every household, as shown by the analysis earlier in this paper; for other households, on the other hand, the benefits are financially worthwhile.

Smart subsidies

How best to use subsidies to address market constraints while delivering public services is a worldwide concern. Well-designed subsidies should be able to catalyse systemic change and accelerate technology adoption without distorting the behaviour of the target beneficiaries. Ideally, they should help create conditions to leverage additional investments and financial solutions that will not require recurrent subsidies over time. A subsidy can be considered effective if it can be withdrawn without the end-user noticing the impact either in price of products or the level of services. When designing a subsidy scheme, it would be good to bear in mind the phase-out or exit strategies and their potential impact. It is likely that an exit strategy for subsidies was not pre-formulated in the national rural biogas programme of China, and therefore the sudden withdrawal of biogas subsidies would have a significant impact on the development of China's domestic biogas.

Smart subsidy schemes have been used by various projects in different sectors, such as agriculture, water supply, public housing, and rural telecommunications. These practices could offer inspiration to the domestic biogas programme in improving the cost-effectiveness of subsidies.

5.3 Enhancing the pro-poor component of biogas development

The current subsidy schemes that support domestic biogas construction in rural China differentiate between different levels of income from one region to another, but mostly fail to address income disparities within a region or a community. While this makes it easier for implementing agencies to identify potential project households, and avoids the socially sensitive task of classifying households by income level, this arrangement may exclude some households in the poor and lower-middle income categories from taking advantage of government subsidies to build a biogas digester, even though these households are the group most likely to benefit from this technology. However, subsidies may lead poor households to misplace their spending priorities, if they take the opportunity provided by a subsidy to build a biogas digester but then have difficulty running it. On the other hand, some high-income households may be motivated by subsidies to invest in biogas construction, but not be willing to do the follow-up work and maintenance.

The 'village-based' promotion of biogas construction (involving most households in a given village, rather than disparate households on an ad hoc basis) helps achieve economies of scale and cuts down project operational costs, but it may also block some households' access to government subsidies. When some households have favourable conditions for biogas production, but their village as a whole does not meet the criteria of 'village-based' promotion, those households would not be eligible for funding. Households in those villages yet to be covered rarely invest in biogas construction wholly at their own expense, but rather wait for the arrival of subsidies.

There is no right or wrong way to promote biogas installation, be it by subsidising high-income rural households to construct biogas digesters, or by providing subsidies for village-based approaches to biogas installation. The important thing is for the intervention to deliver economic benefits. From a social perspective, however, any alternative methods should be explored in order that public resources can best provide timely assistance and maximise benefits towards the groups who most need them. In many cases, public investments have to make trade-offs between prioritising efficiency or fairness. As significant disparities exist in rural China, poor and lower-income households may not be able to afford biogas construction, yet they may be able to do the work of taking care of the domestic biogas digesters and supply enough feedstock. Pro-poor arrangements should be explored to tackle this problem. A pro-poor component could be in the form of more grants for low-income households, or more effective social biogas services, or improved technical support.

5.4 Closing remarks

China's domestic biogas programme has reached around a quarter of rural households and benefits about 100 million people. Strong investment from the national and local governments and the financial assistance from international organisations have played an important role in its large-scale dissemination. A variety of biogas systems are available in different regions of the country to enhance the multiple benefits of domestic biogas.

Rapid economic development and the equally rapid process of urbanisation across the country have brought major changes to the domestic biogas development context. Lack of feedstock for biogas production at household level, lack of available labour for the operation and maintenance of biogas digesters, and inadequate technical and operational services to biogas user households have all emerged as challenges. As the financial performance and market competitiveness of domestic biogas digesters are not always satisfactory, all these factors together have resulted in a large number of biogas digesters either functioning below their full potential or not being used at all. To tackle these problems, the national biogas programme has been exploring countermeasures, such as rural biogas service networks, alternative feedstock (such as agricultural residues like wheat or rice straw), extending the value chain of domestic biogas digesters, and introducing community-scale biogas plants.

As the socio-economic benefits of domestic biogas digesters outweigh their direct financial benefits for households, the government has heavily subsidised the construction of biogas digesters and operational services to biogas user households. In this new context, it is worth reviewing and updating the parameters and assumptions used to assess the economic performance of domestic biogas digesters, in order to confirm that government subsidies are indeed justified.

It seems that domestic biogas development in China is now at a crossroads and government investment is likely to decline. It is questionable whether the momentum in biogas development can be maintained in the future, or if the scale of biogas use in rural China can be sustained without subsidies. Generally speaking, subsidies can be a double-edged sword – they may promote social welfare by correcting market failures, or distort the behaviour of market players, which in turn may lead to inefficiencies. While avoiding one-size-fits-all approaches, due efforts should be made to maximise the efficiency and cost-effectiveness of government subsidies.

Given the financial performance of domestic biogas digesters and the significant income disparities across rural areas, rural households have differed widely in their willingness and ability to pay for the construction and operation of domestic biogas digesters. The poor and lower-middle income households in less developed areas have struggled financially to invest in biogas projects. If the economic viability of domestic biogas digesters can be assured, then pro-poor arrangements should be enhanced to better promote inclusive socio-economic development.

From a broader perspective, small-scale biogas technologies can be an appropriate technology for rural areas of many developing countries. Leaving aside biogas's multiple benefits, if the majority of the rural population in developing countries were to shift their primary energy supply from local renewable energy sources to commercial fossil fuels, it would have a huge economic and environmental impact; it could affect the security of energy supplies at a national or even global level. For this reason, due efforts should be made to overcome the various barriers and emerging difficulties to create a more favourable enabling environment for the robust and sustainable development of the biogas sector.

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China's domestic biogas programme has now reached around 100 million people, supplying a quarter of rural households with biogas digesters. This technology allows households to convert manure into clean cooking fuel and organic fertiliser, providing an effective and non-polluting alternative to fossil fuels, firewood, and chemical fertilisers. Strong investment from the national and local governments and financial assistance from international organisations have played an important role in the large-scale dissemination of biogas technology, and a variety of biogas digester models have been developed in different regions of the country.

It seems that domestic biogas development in China is now at a crossroads, and government investment is likely to decline. Government subsidies can be a double-edged sword – they may promote social welfare by correcting market failures or distort the behaviour of market players, which in turn may lead to inefficiencies. Without one-size-fits-all solutions, due efforts should be made to maximise the efficiency and cost-effectiveness of government subsidies.

From a broader perspective, small-scale biogas digesters can be an appropriate technology for rural areas of many developing countries. Leaving aside biogas's multiple benefits, if the majority of the rural population in developing countries were to shift their primary energy supply from local renewable energy sources to commercial fossil fuels, it would have a huge economic and environmental impact; it could affect the security of energy supplies at a national or even global level. For this reason, due efforts should be made to overcome the various barriers and emerging difficulties to create a more favourable enabling environment for the robust and sustainable development of the biogas sector.

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