Small-scale bioenergy projects in rural China: Lessons to be learnt

Jingyi Han, Arthur P.J. Mol, Yonglong Lu, Lei Zhang

Abstract

Large amounts of small-scale bioenergy projects were carried out in China’s rural areas in light of its national renewable energy policies. These projects applied pyrolysis gasification as the main technology, which turns biomass waste at low costs into biogas. This paper selects seven bioenergy projects in Shandong Province as a case and assesses these projects in terms of economy, technological performance and effectiveness. Results show that these projects have not achieved a satisfying performance after 10 years experience. Many projects have been discontinued. This failure is attributed to a complex of shortcomings in institutional structure, technical level, financial support and social factors. For a more successful future development of bioenergy in rural areas, China should reform its institutional structure, establish a renewable energy market and enhance the technological level of bioenergy projects.

1. Introduction

Bioenergy is receiving significant attention recently, for various reasons. First, it is celebrated for its potential contribution in mitigating greenhouse gas emissions. Second, it can contribute to alleviating rural poverty by additional sources of income. Third, it is believed to increase energy security by lowering oil import dependencies of countries and regions (Mol, 2007; Verdonk et al., 2007). While first generation large-scale bioenergy production from food crops as maize, oil palm and sugarcane is increasingly meeting severe criticism for its detrimental effects on the environment (biodiversity, soil and water deterioration and NOx emissions) and food access, small scale and second generation (from biodegradable waste and plant left-over) are considered more favorably (Mol, 2007).

While China has recently become involved in large-scale biofuel (bioethanol and biodiesel) production, it has a much longer history of small-scale bioenergy production, especially in rural areas. Especially since the end of the 1980s, bioenergy has been identified as an important and promising contributor to renewable energy production and rural development. Renewable bioenergy technologies that were widely applied from the early 1990s onwards included anaerobic digestion, pyrolysis gasification, biofuel solidification, bioethanol generation and biodiesel cogeneration (Johansson et al., 1993). Being still predominantly an agricultural country, China has plenty of biomass resources for bioenergy development. It is estimated that China produces 0.2–0.4 billion tce of non-product biomass available for energy purposes every year (Li et al., 2001; Li and Hu, 2003), most of it in rural areas.

Due to low levels of economic development in China’s rural areas, pyrolysis gasification has been among the more popular technologies, as it is a rather simple technology and cheap compared with other bioenergy technologies. Around the year 1997, China started several rural biogasification demonstration projects under its agreement with European Union (Bridgwater et al., 1999; MOA/DOE Project Expert Team, 1999). In 1998, about 200 village-level biogas stations were established in China (Zhou, 2002), and 7 years later more than 1000 village-level biogas stations have been constructed through national investment, mainly in the rural areas of eastern and south-eastern coastal provinces such as Liaoning, Shandong and Zhejiang (Leung et al., 2004; National Renewable Energy Laboratory, 2006). These projects aim to provide village residents access to clean and cheap energy and to improve local air quality by reducing direct combustion of straws and stalks. Ten years have passed since China constructed its first small-scale biogas station, but anecdotal evidence suggests that the amount of functioning biogas stations has declined strongly.

Against the above-mentioned background, this paper aims not just to assess the performance of these low-technology bioenergy projects, but especially to explain how and why the set targets for these projects were not met. These insights are used to put forward suggestions for decision makers to improve the performance of these technologies. In doing so, the paper focuses on coastal Shandong Province, where biogasification projects have
been introduced widely. Section 2 introduces Shandong Province (its renewable energy demand, available biomass resources, and its institutional and policy frameworks) and the biogasiﬁcation technology used. Section 3 reports on a performance analysis of seven biogas stations in Jinan City, Shandong Province. Sections 4 and 5 analyze the causes and barriers that resulted in the poor performance of biogasiﬁcation in Shandong Province. Finally, recommendations for future development of rural bioenergy utilization in China are formulated in Section 6.

2. Bioenergy in Shandong Province

2.1. Demand for renewable energy

Shandong is among the largest energy-consuming provinces in China. In 2004, its total energy consumption climbed to 0.159 billion tce, ranking the second in all China’s provinces and for the ﬁrst time exceeding its total energy production (Shandong Statistical Bureau, 2005). In the national economic development objectives, China’s average annual growth rate of energy demand is estimated to be 2.8% for the coming 50 years (Wang and Lu, 2002). In other words, total energy consumption in Shandong will reach 0.566 billion tce in the year 2050, if the growth of energy demand in Shandong keeps up with the estimated national rate.

At the same time, energy production in Shandong will not signiﬁcantly increase if the current energy industry structure remains unchanged. Statistical data even show that coal production in Shandong in 2004 was 1.3% lower than that in 2003 and the production is believed to shrink further in the coming years (Gao and Gao, 2005). Although oil production is relatively stable (with 37.5% of oil products exported to other provinces), Shandong produces 6% of the total national oil production every year but has only 2.2% of the total national reserve. Its oil resources will be ﬁnished within the next 20 years.

Like most provinces in China, Shandong has a “fossil-fueled” energy structure, where coal (76.0%) and oil (23.3%) account for 99.3% of total primary energy consumption (Shandong Statistical Bureau, 2005). This “fossil-fueled” energy structure has two negative effects. First, it releases large amounts of greenhouse gases. In 2004, about 10% of China’s waste gas emission occurred in Shandong (National Bureau of Statistics of China, 2005). Second, it causes spilling of energy. In China, fossil fuels are mined, processed and consumed at lower efﬁciencies compared with renewable energy resources. Most fossil-fuel-producing areas are located in its northwest and northeast China, while the major industrial areas and cities lie in east and southeast China, resulting in fuel transports over long distances. According to statistical analyses, approximately one-fourth of China’s primary energy is wasted during mining, processing and transportation (National Bureau of Statistics of China, 2006).

There is increasing recognition among Chinese scholars and state ofﬁcials that future energy shortages in Shandong cannot be solved simply by enhancing oil and/or coal mining (and imports), but need to involve a change of energy structure by enhancing the share of clean and renewable energy. The growing strictness of national and local environmental protection needs and targets only reinforce this. Biomass has a large potential to become a major renewable energy source for Shandong.

2.2. Biomass resources in Shandong

Agricultural biomass and forestry biomass are two main resources for bioenergy production. Agricultural biomass refers to agricultural product residues and agro-food-processing wastes. Crop straw, rice husk, corncob and corncob are often mentioned as useful biomass for energy generation. Forestry biomass is produced during forest growth, harvest and wood manufacturing.

The agricultural sector in Shandong provides considerable amount of biomass resources, although no detailed investigation has been conducted yet. According to Bridgwater et al. (1999), production of crop residues is related to amounts of crop-products and rates of residues produced from crops. The amount of residue from a speciﬁc crop can be estimated as follows:

\[
BR = G \times r
\]

where BR is the amount of biomass residue from a crop, G is the amount of production of this crop and r means the rate of residue biomass produced from this crop.

Thus, the total amount of biomass residue from crops in Shandong in 2004 is 67,322,676 tce (cf. Table 1). With pyrolysis gasiﬁcation technology, 2.5 kg biomass is enough for a normal family to cook meals for a whole day. In other words, one-fourth of the total crop residue production, 18,250,000 tce, can provide the 20 million rural families with sufﬁcient fuels for cooking. This to some extent competes with the use of crop residues as animal fodder, industrial materials and fertilizers in Shandong. But it is estimated that currently about 20% of crop residues are burnt directly in the ﬁeld as waste, which could in stead be used as bioenergy without conﬂicts for other use functions.

According to studies conducted by the Food and Agricultural Organization (FAO) of the United Nations, only half of the forestry harvest is used for industrial products at mills and manufacturing facilities (UNEC/FAO, 2006). Thus, 50% of forest biomass, in the form of branches, barks, chips and sawdust, is available for energy production. In 2004, 1,288,358 m³ of forestry products were harvested in Shandong (Shandong Statistical Bureau, 2005), offering 644,179 m³ forestry biomass for energy production.

2.3. Institutions and policies for renewable energy development

In Shandong Province, four major departments under the People’s Congress (PC) and provincial government share power on renewable energy development (Fig. 1). The Environmental Protection Bureau (EPB) is responsible for enforcing national environmental laws and policies, specifying local pollution standards, investigating environmental accidents and mediating environmental disputes. The Natural Ecosystem Protection Section (NEPS) under EPB takes responsibilities of directing comprehensive utilization of straws and monitoring improper combustion. The Rural Development Section (RDS) under the Department of Science and Technology (DOST) funds and organizes advanced-technology demonstration projects in rural areas, including renewable energy promotion projects. The Energy

| Table 1 Estimation of crop residue production in Shandong, 2004 |
|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Wheat          | Corn          | Cotton         | Peanut          | Soybean         | Potato         |
| Area (ha)      | 3,105,700     | 2,455,049      | 1,059,207       | 925,298         | 241,180        |
| Yield (kg/ha)  | 5102          | 6106           | 1036            | 3948            | 2972           |
| G (t)          | 15,845,638    | 14,991,484     | 1,097,709       | 3,653,002       | 716,674        |
| r (kg/kg)      | 1             | 2              | 3               | 3               | 2.5            |
| BR (t)         | 15,845,638    | 29,982,968     | 3,293,127       | 7,306,004       | 1,075,011      |

* N/A: not available.
and Communication Section (ECS) under the Development and Reform Commission (DRC) develops policy measures for improving energy efficiency and promoting new energy in the framework of provincial socio-economic development plans. The Eco-Agriculture Section (EAS) under the Department of Agriculture (DOA), which is also called the “Office of Rural Renewable Energy Development of Shandong”, forms the most important governmental agency for renewable bioenergy development in Shandong. It takes full responsibility for organizing, planning and implementing renewable energy projects in rural areas.

Shandong government develops renewable energy policies at provincial level, as supplement to or specifying national renewable energy policies and standards. These provincial policies entail regulatory instruments, financial incentives and technical standards for renewable energy development. The most important policies are summarized in Table 2.

2.4. Biogasification projects in Shandong

The urgent demand for renewable energy development, availability of biomass resources, and well-established institutional and policy framework enhanced the blossoming of bioenergy demonstration projects in Shandong. Around the year 1997, China started with bioenergy demonstration projects in rural areas and Shandong has been one of the key implementation provinces. By 2005 Shandong province had constructed over 400 village-level bioenergy projects. Pyrolysis gasification technology was widely applied in these stations, because it was the most mature one at the end of the 1990s, while the cost to construct a biogas station are relatively low. As such, it perfectly matched the need of developing renewable energy resources in rural areas, where financial constraints are large.

Pyrolysis gasification is suitable for treating various biomass materials, such as corn stalk, sawdust, wood chips and crop straw. The entire pyrolysis gasifier consists of four components: the feeding system, the gasifier, the steam generator and the gas storage facility (cf. Fig. 2). The pyrolysis gasification process includes two stages (Leung et al., 2004; Li and Hu, 2003; Sun et al., 1992). At the first stage, workers put biomass into the feeding system. Then the feedstock is transferred into the gasifier and becomes fluid in it. The diameter of feedstock can range in size between 0.25 and 250 mm. Biomass undergoes partial combustion at a temperature above 800 C in absence of oxygen, to produce volatiles (mainly carbon dioxide and water vapor) and charcoal. At the second stage, charcoal transforms the volatiles into CO, H2 and CH4. After three rounds of purification, a mixed fuel gas is obtained, consisting of CO, H2 and CH4. This mixed gas is stored in a gas storage facility and transported via underground pipes to individual families. The entire process operates in batches.

### Table 2

<table>
<thead>
<tr>
<th>Policy</th>
<th>Promulgateor</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation on rural energy development and management in Shandong Province</td>
<td>People’s Government of Shandong Province (1997)</td>
<td>Article 12: Governmental departments of rural energy development should organize production and utilization of new and renewable energy in suitable areas.</td>
</tr>
<tr>
<td>Executive order on energy conservation in Shandong Province</td>
<td>The Standing Committee of the PC of Shandong Province (2002)</td>
<td>Article 29: … Development of new and renewable energy, such as biogas, solar energy, hydropower and wind power, is encouraged.</td>
</tr>
<tr>
<td>Circular on ensuring the quality of rural energy development projects in Shandong Province</td>
<td>The Department of Agriculture of Shandong Province (2005)</td>
<td>… Select villages and households who have husbandry experience, good economic condition and willingness to use biogas, to carry out the “One Pool with Three Transforms” project.</td>
</tr>
<tr>
<td>Standards of “One Pool With Three Transforms” rural energy project in Shandong Province</td>
<td>The Department of Agriculture of Shandong Province (2005)</td>
<td>… Households involved in the project should construct a biomass digester and reform the kitchen, toilet and pigsty.</td>
</tr>
</tbody>
</table>

![Fig. 2. Process of biomass pyrolysis gasification.](http://www.shandong.gov.cn/col/col5487/index.html)
governmental and other sources, making a large-scale quantitative survey impossible.

However, the nature of case study research brings limitations, especially with respect to the generalizability of the outcomes. By cautiously selecting our cases, we have tried to minimize this risk and maximize the value of the case study outcomes for a wider constituency of projects. A district in Jinan City, Shandong Province was carefully selected for the in-depth case study analysis. This district was selected based on following reasons. Firstly, this is a representative rural area in Shandong in terms of economic development, the importance of agriculture versus other economic sectors, demography and natural environment. Most residents are involved in agricultural production, making up 9.7% of local GDP in 2005. The average annual family income is just below 20,000 Yuan (€2000) (Shandong Statistical Bureau, 2005), which is about the average for the province. Secondly, all the small-scale biogas stations in Shandong were constructed under the same project, which aimed to alleviate atmospheric pollution caused by direct burning of staks in the side-fields along Jinan-Qingdao Highway and Jinan Airport Highway. In comparison with other areas, the selected district has the highest density of stations and the longest project history (seven stations were constructed during the period 1996–2005). This enabled us to evaluate longer running station and at the same time keep a number of variables constant. Thirdly, all the seven stations in this district used pyrolysis gasification technology, which is the most prevailing technology of biogas stations in China. This made the results relevant for other projects using similar technologies, while excluding technology as an explanatory variable. For these reasons, we can expect that the outcome of our case studies have relevance for other pyrolysis gasification cases in rural Shandong Province.

Table 3 provides—as far as available—the basic data for each case study station, which is named after the village where it locates. Scales of these stations vary: the smallest station provides 110 families with biogas for cooking and heating, while the biggest one supports 1000 families. Four out of the seven had been discontinued by the time of fieldwork (July 2006). SZY station was under reconstruction during our fieldwork, to become an electricity plant that uses biomass as fuel. SSC is the only station, which received funding from China's Ministry of Agriculture. All stations received free experimental equipment from Shandong Academy of Sciences or Shandong University. Each household who applied (voluntary) for using biogas was charged 300 Yuan (€30) for installation of pipes, a biogas stove and a meter registering biogas consumption.

The total investment of a single station relied heavily on its scale: the larger the scale is, the more expensive the investment is. In China, normally construction cost of a biogas station with capacity of 200 families ranges between 0.5 and 2 million Yuan (€50,000–200,000; Bridgwater et al., 1999; Li et al., 2001). Construction costs per capacity of 200 families of the case study stations were as follows: SSC—0.6 million Yuan; XJL—0.73 million Yuan; CXC—0.75 million Yuan and YJC—0.64 million Yuan. This is all at the low end of the range of construction costs for China pointing at a cost-efficient way of construction.

During operation of the seven biogas stations, no financial support was received from higher level governments. It was the village government's full responsibility to run the station financially healthy. In most cases, the village government appointed one village official as station manager and hired two workers. The village government had authority to decide the price of biogas; higher level governments gave no directions. Most villages set the price at a low level, comparable to the level of the neighboring village, to prevent complaints from villagers. The purchase of fuels, house rent, electricity, workers' salary and

<table>
<thead>
<tr>
<th>Biogas station</th>
<th>Construction time</th>
<th>Initial investment (106 Yuan)</th>
<th>Capacity (families)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shasancun (SSC)</td>
<td>2002</td>
<td>3.0</td>
<td>1000</td>
<td>In good condition</td>
</tr>
<tr>
<td>Xiaolujia (XJL)</td>
<td>1998</td>
<td>0.4</td>
<td>110</td>
<td>In use</td>
</tr>
<tr>
<td>Xiaozhangma (XZM)</td>
<td>2004</td>
<td>N/A*</td>
<td>N/A</td>
<td>Discontinued in 2005</td>
</tr>
<tr>
<td>Nanguoer (NGE)</td>
<td>2000</td>
<td>N/A</td>
<td>330</td>
<td>Discontinued in 2003</td>
</tr>
<tr>
<td>Chengxicun (CXC)</td>
<td>1997</td>
<td>0.98</td>
<td>260</td>
<td>Discontinued in 2004</td>
</tr>
<tr>
<td>Shiziyuan (SZY)</td>
<td>2005</td>
<td>1.5</td>
<td>N/A</td>
<td>Under reconstruction</td>
</tr>
<tr>
<td>Yanjiaacun (YJC)</td>
<td>1996</td>
<td>0.96</td>
<td>300</td>
<td>Discontinued in 1999</td>
</tr>
</tbody>
</table>

* N/A: data not available.

4. Assessing the performance of bioenergy projects

4.1. Economy of the bioenergy projects

In principle, all stations were funded by the provincial government, the village government and other organizations, as agreed in contracts between the provincial government and village governments. Villages were carefully selected so that they could afford their part of the initial investment. Other organizations funding the projects include the national government, the municipal government, external corporations and research institutes. SSC is the only station, which received funding from China's Ministry of Agriculture. All stations received free experimental equipment from Shandong Academy of Sciences or Shandong University. Each household who applied (voluntary) for using biogas was charged 300 Yuan (€30) for installation of pipes, a biogas stove and a meter registering biogas consumption.

4.2. Engineering performance

...
occasional repairs were all paid from the village government account. Every half year the station manager collected money from the villagers for the biogas they consumed, which formed the main income of the station and was put into the village government account. At the end of the year, the village government compensated any deficit. None of the seven stations could provide detail account records of its daily operation. Income and expenditures were recorded just as a single item on the community government’s account, resulting in poor (financial) transparency. With the assistance of the station manager of XLJ station an estimation was made of expenditures and income of this biogas station in 2005 (see Table 4), suggesting a significant annual government subsidy.

4.2. Technological performance of the bioenergy projects

Major outputs of the bioenergy projects included the installation of equipments such as biomass gasifiers, pipes and biogas stoves. Of the seven stations, XZM, NGE, CXC and YJC were discontinued shortly after their construction (see Table 3). SZY is being rebuilt into an electricity plant that uses biomass as fuel. XLJ was still in use, although, the station had to be discontinued for several days every 2–3 months due to technical problems. SSC was the only station that was still functioning properly. Most stations only used about half of the designed capacity during operation.

During operation, the gasification equipment faced various problems. Tar was the most serious problem. Equipment was regularly jammed by tar, which is very difficult to get rid of when it has coagulated on the inner surfaces of pipes and containers. In some villages workers had to open the equipment and clean them every week. This is time and money consuming. Another annoying problem with the gasification equipment consisted of biogas leakage from pipes. Biogas contains CO and CH₄, which are hazardous to human health. Therefore, leakage needs to be prevented or quickly mitigated. Because all pipes were placed underground, leakage resulted in high costs for repair and pipe replacements.

Average caloric value of biogas produced in these stations is only 5316 KJ/m³, much lower than other fuels (Fig. 3). As a result, users have to consume a higher volume of biogas than other fuels to cook the same meal. A consequence is that stations need large storage facilities. Normally workers in biogas stations run the equipment and fill the gas storage twice a day, which provides enough biogas for all users to cook meals for a day. If the caloric value of biogas could be doubled, the storage capacity could be halved or workers only needed to fill the storage once a day, saving costs.

A final problem is that the gasification equipment cannot treat wet fuel, as it harms or even damages the steel equipment. Some rich villages such as SSC and SZY built extra buildings for storing fuels, while in others workers had to spend a lot of time drying wet fuels. During the raining seasons, these stations were often forced to stop producing biogas, due to a lack of dry fuels.

4.3. Effectiveness of the bioenergy projects

The available government documents often provide no concrete quantified objectives of bioenergy demonstration projects. Even the recently issued national policy, the Mid-Long Term Plan of Renewable Energy Development, only provided six rather general objectives for bioenergy development in rural areas. Nevertheless, the motivation for bioenergy projects in Shandong Province was clear: besides cheap energy production, the main goal was to alleviate air pollution caused by local farmers burning straw along highways. However, no quantified targets were set on both objectives, making them too vague for a quantified effectiveness evaluation. As a result, only qualitative judgments can be made.

4.3.1. Institutional effectiveness

Institutional effectiveness relates objectives to government outputs for bioenergy utilization, including the establishment of bioenergy projects and the managing of biogas stations. This research assessed government performance in relation to initial objectives of biogas project.

Approximately 365 million Yuan (£36.5 million) was budgeted by both national and provincial governments for constructing biogas stations in Shandong. Village governments also supported bioenergy projects. When Shandong government planned the project in Jinan City, more than 20 villages applied to be sites for bioenergy demonstration projects. After an evaluation—with criteria such as village scale, economic level, distance to highways and availability of biomass resources—seven villages were selected. Subsequently, opinions of villagers in these seven villages were collected regarding, among others, their willingness to install a biogas stove and the costs for biogas they could afford.

Table 4

<table>
<thead>
<tr>
<th>Expenditures</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Amount</td>
</tr>
<tr>
<td>Purchasing fuels</td>
<td>60,000ᵃ (200 Yuan/t × 300 t)</td>
</tr>
<tr>
<td>Electricity bill</td>
<td>15,075 (0.67 Yuan/kWh × 22,500 kWh)</td>
</tr>
<tr>
<td>Workers’ salary</td>
<td>19,200 (9600 Yuan/worker × 2 workers)</td>
</tr>
<tr>
<td>Repair cost</td>
<td>2000</td>
</tr>
<tr>
<td>Depreciation of equipments and buildings</td>
<td>40,000ᵇ</td>
</tr>
<tr>
<td>Total</td>
<td>136,275</td>
</tr>
</tbody>
</table>

ᵃ Corn stalks bought from farmers as fuel.
ᵇ The initial investment of XLJ station was 0.4 million Yuan. It was designed to be used for 10 years.

Fig. 3. Caloric values of different fuels (KJ/m³). Source: Bridgewater et al. (1999).
Visits to neighboring villages with running biogas stations were organized for villagers. Their final opinions directed the design and capacity of the individual projects. All seven biogas stations have been delivered, but it sometimes with delay.

But significant ineffectiveness emerged during the running of the projects. During interviews staffs in EAS of Shandong DOA, who are supposed to take full responsibility for renewable bioenergy projects in rural areas, could not give clear answers to basic questions such as how many stations had been built or which institutes were doing research and development on bioenergy. Communications between Shandong authorities and village governments were poor. For instance, no Shandong department “in charge” was informed 2 years after the NGE village government discontinued the biogas station and sold the equipment. In case of emergencies around biogas projects, it always took a long time to decide who had responsibility and where necessary financial and technical resources for repair could be obtained. In addition, no monitoring and evaluation mechanism was established to follow and investigate the status of the stations. It seemed that for Shandong Province, bioenergy projects ended not when local people were provided stable biogas provision, but when it was reported that the construction of the station was finished and this good news was released to the media. Several stations had no other function than to “demonstrate” the ability to construct a project.

4.3.2. Target group effectiveness
Most villages in Shandong showed a strong willingness to establish bioenergy projects. By the end of 2005, Shandong Province alone had constructed more than 400 biogas stations. Although several of our case study stations were shut down, all village leaders interviewed expressed strong interests in continuing the projects if financial conditions and technical support were improved. But citizens in these villages did not show the same enthusiasm. The average proportion of families that applied for using biogases was below 50% in all the seven villages. A large number of villagers expressed their reluctance to pay the 300 Yuan for installation of pipes and stoves, which prevented many families from using biogas. Nevertheless, fewer families burned straw and stalks, even after bioenergy projects discontinued. This change in behavior relates to two mechanisms. Villagers found that the air quality improved during the period they used biogas and thus did not turn back to biomass burning in the field after discontinuation of bioenergy projects. And during the first years of the new millennium the government posed stronger enforcement and sanctions on burning biomass in the field. Currently, most biomass not used in bioenergy projects is used as fertilizer or as feedstock for livestock, and a small amount is still used as fuel in traditional stoves. Much less burning in pen air takes place nowadays.

4.3.3. Impact effectiveness
One important purpose of constructing biogas stations in Shandong was to improve local air quality. Crop stalk and firewood were once traditional energy resources for rural household in Shandong mainly for cooking and heating. In the 1990s, energy from crop stalk and firewood accounted for about 80% of rural energy consumption. With rapid development of economy, the rural energy consumption is increased while energy structure changed. The consumption of commercial energies such as electricity, coal, gas and oil increases rapidly, especially in the coast areas and vicinity of large cities. The consumption of energy from crop stalk and firewood decreases sharply. It is estimated that crop stalk consumption for rural residential in Shandong decreased from 33.5 million tons in 2000--28.8 million tons in 2004 (China Statistical Bureau, 2006). As a result, a considerable amount of crop stalk is directly burnt in the harvest period by farms, leading to serious air pollution (Li et al., 1999).

After implementation—of course also of biogas stations outside our case study area—air quality in Jinan City was significantly improved, and that remained even after the discontinuation of several projects. Fig. 4 suggests a causal relation between the start of these biogas stations and reduction of concentrations of three air pollutants (SO2 for 65.3%, NO2 for 70.7% and PM10 for 69.5%). Within the same period, average pollutant concentrations in other areas without bioenergy project reduced much more slowly (SO2 for 35.9%, NO2 for 29.4% and PM10 for 61.1%). Although we cannot exclude other factors, such as the change of industrial structure, enhancement of energy efficiency or the stringency and enforcement of environmental policies, that improved local air quality over the years 1997 till 2005, bioenergy projects did contribute to lower air pollutant concentrations in two ways. Firstly, they reduced burning of crop stalks in open air, which directly contributed to air quality improvement. This is clearly the most important reason, as it continued even after most projects ended. Secondly, the biogas stations reduced the consumption of fossil fuel. In comparison with fossil fuels, biogas production, transportation and consumption is more environmentally friendly. Biogas releases less harmful waste when being processed compared with coal and oil (although it has small amounts of byproducts of tar and ashes, which are usually dumped locally).

4.3.4. Societal effectiveness
Normally societal needs are not stated directly in policy objectives. However, societal needs are fundamental driving forces for policies and projects. Therefore, societal effectiveness of these projects was also assessed, as the degree to which the projects contributed to societal needs.

Local farmers obtained economic benefits from the biogasification implementation. First, these projects provided them cheap energy resources. Every family only needed to pay 300 Yuan for installation of pipes and a stove, and on average 0.20 Yuan/kg for consumed biogas. According to rough estimations, a family could thus save 740 Yuan annually on energy consumption. Second, these projects offered farmers new sources of income. In most villages with a biogas station, farmers could sell their straws and corn cobs to the station at prices around 0.20 Yuan/kg. For an individual farmer family this could mean annually several hundred Yuan of extra income. Third, opportunities were created for new employment and business, including biogas station workers, equipment producers, station builders and contractors, and biofuel traders. Upgrading the technological level to generate
electricity, as in the case of SZY, increases the need for more well-educated and skilled employees.

Bioenergy projects provided rural residents clean and safe biogas for cooking and heating. After the installation of a biogas station, straws were no longer piled all over in the villages, and sooty kitchens and chimneys disappeared. Villagers felt living a modern lifestyle, similar to urban residents using piped gas. This motivated them to improve other aspects of their daily life. Using biogas also reduced the chance children caught injured or burnedally, people in rural Shandong had to spend significant time on gathering straws, tree branches and waste wood for fuel. Even after coal was introduced for cooking in rural areas, buying and transporting coal from outside the village and heating the coal stoves remained time-consuming tasks, especially for women. Using biogas saved time. As local people indicated, after the introduction of bioenergy project, “only two persons are busy firing the gasifier when the whole village is cooking”.

5. Causes of bioenergy project failure

Overall, our performance evaluation shows at best mixed results. While stations have been established and environmental impacts seem to have improved, four out of the seven stations were out of use during our investigation. Extrapolating this proportionally, less than 200 stations would have survived in Shandong Province. But our search for biogas projects indicates much smaller numbers. What are the main shortcomings that contributed to these project ambivalences? Our research, as well as experiences from other countries (Katinas and Markevicius, 2006; Nilsson et al., 2006; Prasertsana and Sajjakulnukit, 2006), found five causes that resulted in the failures of rural bioenergy projects.

5.1. Institutional shortcomings

Renewable energy development in China is co-managed by a number of agencies, both at the national level and at the local level. These governmental departments work under different national ministries and have different interests in developing renewable energy resources. No institutional arrangement has been constructed to encourage harmonious collaboration between these agencies, or to define clear hierarchies. As a result, coordination between different departments is heavily retarded, and responsibilities of each agency with respect to bioenergy development are unclear. All governmental departments are reluctant to monitor the status of biogas stations and to take responsibilities in ensuring project effectiveness. Stations encountering technical problems have no addresssee for requesting financial and technical support. This lack of coordination and division of responsibilities is enhanced by unclear division of responsibilities between the central provincial departments and the local village authorities. These unclear institutional arrangements impose important negative impacts on bioenergy projects in China.

Poor management of biogas stations also reflects the institutional shortcoming.

5.2. Policy shortcomings

In 1986, the National Economic Committee issued the Circular on Improving Rural Energy Development. This was the first policy on renewable energy development that mentioned the importance of bioenergy. However, more than 20 years later no detailed plans have been formulated, no technical standards and guidelines for bioenergy been implemented to regulate the equipment market, and no quantified objectives have been set.

In rural areas, development of bioenergy lacks long-term planning and strategy. Many county and town governments constructed biogas stations not in the framework of a long-term energy policy, but following orders from higher level governments. While most villages had strong enthusiasm for bioenergy demonstration projects, they lacked the authority and resources to formulate long-term energy policies that include these projects.

In recent years, emphasis of bioenergy development in Shandong has been shifted from pyrolysis gasification to marsh gas as the national government does in its most rural areas. Pyrolysis gasification is no longer attracting the interest of government leaders. Infrastructure of marsh gas is cheaper to construct and easier to manage than that of pyrolysis gasification in rural areas (Hall et al., 1992; Klass, 1998; Lettinga and van Haandel, 1993; Ma, 2005). However, marsh gas projects also encounter many problems. In northern China, the temperature is very low in winter, which easily freezes marsh gas pools. There is still no satisfying way to treat poisonous residues, which could cause heavy metal pollution to crops and vegetables. Marsh gas pools produce unpleasant smells. With current technologies, production and use of marsh gas is not safe enough. It was reported that a villager fell into the pool and died in Guangxi Province (6 February 2003); and that a marsh gas pool exploded in Fujian Province (17 August 2007).

Other policies also influenced the implementation of bioenergy projects in rural areas. To push the so-called “Building New Socialist Countryside” campaign, more and more farmland is occupied by new buildings and infrastructure. Farmers lost farmland, and areas of corn and rice plantation reduced. Shortage of biomass resources led to the closing of well-constructed and well-managed stations, such as CXC station. But at the same time government documents still see large-scale pyrolysis gasification projects as important contributions to “Building New Socialist Countryside” (China State Council, 2005).

5.3. Technical shortcomings

Pyrolysis gasification technology was designed and developed 20 years ago, for application in rural areas. Too much attention was paid to lowering costs, with equipment having a simple structure and labor-intensive operation. This had a number of consequences. Insufficient purification devices were designed, which resulted in tar jamming. The equipment could not treat wet fuels. The calorific value of produced biogas was too low. And during construction, no high-quality steel was used and storage facilities and pipes started to rust and leak biogas.

These technical problems prevented pyrolysis gasification from becoming a dominant renewable energy technology in China. Some advanced bioenergy technologies developed in Western countries remained too expensive for rural areas in China. Although domestic research institutes are making efforts to improve these technologies and experiment with electricity generation using biomass (e.g. SZY and other places), it will take some time before pyrolysis gasification technology can meet the technological requirements of today.

5.4. Financial shortcomings

Demonstration projects of pyrolysis gasification were developed mainly for rural areas, where social benefit is more
important than economic benefit. Sufficient financial support, for example, through government subsidy, tax reduction and low interest loans have been necessary for establishing these kinds of projects. External investment to the evaluated projects was for all stations sufficient to launch the biogas station.

Financial problems especially occurred during the running of stations. A biogas station has to pay for fuels, workers' salary, electricity bills, house rent and regular repairs. At the same time, no effective renewable energy market has been established, and biogas was sold at a low price (on average 0.20 Yuan/m³). The annual deficit of a biogas station evaluated in this research is estimated at more than 30,000 Yuan (~$3000), which had to be compensated by the village government (see Table 4). Increasing the gas price would be a logical solution. In order to balance cost and benefit, the gas price should increase around 60%. Village officials—who are in charge of setting gas prices—are reluctant to set higher gas prices, as it is likely to raise strong opposition from villagers and a reduction in biogas consumption. But village budgets for necessary repairs, fuels and salary are limited, also because only a part of the community profit from cheap biogas. SSC station is the only one that received continuous funding from China's Ministry of Agriculture during operation, which made it possible to carry out daily maintenance and further technical improvement. This seems to be a main reason why SSC station is the only station in good condition. Unfortunately, other stations can hardly survive without this kind of continuing financial support from (higher level) governments.

5.5. Lack of public support

Raising gas prices also is difficult as biogas stations did not receive full support from local residents. Changing cooking routines was one of the major obstacles, while advantages of biomass gasification have been insufficiently realized. In some villages, such as YJC, only one-third of the families chose to install and use pyrolysis gasification equipment. This increased infrastructure cost per consumer, while later connections to the biogas infrastructure were significantly more expensive. In addition, quite some villagers refused to pay for the installation of pipes and stove, as they claimed that government promotion of bioenergy in rural areas should come together with free infrastructure. Other villagers were even reluctant to pay for the biogas consumed. In SSC and NGE, many families opened the gas meters installed in their kitchens and destroyed the arithmometer, in order to use biogas “for free”.

This low public support for biogasification had three interdependent reasons. First, villagers' access to information on bioenergy technology was insufficient, resulting in a lack of confidence on the economic and environmental benefits biogasification could bring. Second, on average the income level of rural villagers is low. The prime criterion to judge innovations is direct economic benefit. As sufficient fuels often were locally available for villagers, this resulted in a lack of urgency to use—and pay for—new energy sources. Finally, prices of LPG, coal and electricity were not high enough to economically motivate villagers to change to biogas.

6. Concluding recommendations

According to its long-term plan on rural construction, China will further extend rural utilization of renewable bioenergy. As one of the relatively mature technologies, pyrolysis gasification is believed to play an important role in this. Around the turn of the millennium, biogasification was expected to provide four million tce of energy in rural areas by 2010 (Zhou, 2002). However, the various problems indicated and analyzed above seriously threaten this target; more than incidentally biogas stations have been discontinued shortly after establishment. In this respect, we can formulate three recommendations to overcome the various problems bioenergy projects now encounter, and to further bioenergy development in Shangdong Province and even throughout rural China.

First, it is essential to reform the institutional structure governing bioenergy projects. The spreading of bioenergy responsibilities over too many governmental institutions, with hardly any coordination, clearly frustrates effective development and implementation. Given the cross-departmental nature of bioenergy development, concentrating the responsibility for bioenergy development in one department seems not feasible. The establishment of interdepartmental working groups, both at national and provincial levels, consisting of representatives from the relevant departments and with clear mandates, could improve coordination and responsibility allocation. Such working groups should be in charge of distributing responsibilities regarding renewable energy, coordinating and harmonizing cooperation between governmental sectors and levels, formulating clear objectives and monitoring implementation and distributing (financial) resources.

Second, an effective renewable energy market infrastructure should be established. Bioenergy technology is still a novelty that emerges in technological and market niches. It functions as a small addition to the existing energy system, and is far from competitive in a normal energy market. But at the same time, it needs to function in a market structure, with price competition, cost recovery and efficiencies, and not as a fully subsidized government program. Consequently, a special renewable energy market would be a logical space, until bioenergy technology matures and is capable to compete with conventional energy technologies. As such, bioenergy can compete with other renewables. In such a renewable energy market, price setting of energy is somewhat higher than in the conventional energy market. Financial policies, including government subsidy, low interest loan and tax reduction, could take care of that. But full cost recovery, competition between alternative technologies and arrangements, efficiencies and consumer satisfaction have to become integral parts of such a semi-protected market.

Finally, the technology and management structure of biogas stations need further development and improvement. The current low-technology, community-based bioenergy utilization is too inefficient. This requires of course large efforts in research and development on bioenergy, a tendency that can already be identified, and not only in China (cf. Mol, 2007). But it requires also a better assessment of the scale of bioenergy production under various socio-economic and environmental conditions and context. Small-scale household-level gasifiers need less socio-material infrastructure, are less vulnerable, require simple management structures and can therefore be more efficient in certain contexts. In other situations, large-scale high-technology industrial bioenergy plants might be prevalent. Gasified biomass can be processed with advanced conversion technologies to produce electricity or co-generate electricity and heat, a well-know technology (Williams and Larson, 1993). And second-generation liquid biofuel technologies are currently being experimented in various countries. Standardized community-based, low-technology biofuel technologies are not necessarily the best solution in all situations in rural China.

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