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Anaerobic digestion and community development: A case study from Hainan province, China

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Abstract Connections and relationships between conservation practices and community development in relation to rural sustainability have received considerable attention in recent years, especially in developing countries. Among many sound practices around the world, anaerobic digestion (AD) technology has long been encouraged as an alternative source of energy, while contributing to resource conservation and economic development initiatives in developing rural areas. Guided by the theme of sustainable development, the study examined the current applications of AD technology in Meiwan Xincun Village (MWXCV) in Hainan Province, China. Employing a self-administered questionnaire survey, face-to-face interviews and on-site observation, the study explored the diffusion process, current operation and local impacts of AD practice. The study identifies that leadership, education, technical support and local economy are key factors affecting the diffusion of AD, and governmental financial incentives are significantly effective measures to make the technology economically viable for local residents. The technology was found to fit into the rural livelihood system of the village, with considerable environmental and socio-economic benefits. Guided by the leaders of the village, the local residents generally accept and support the practice and are willing to contribute to introducing the technology in and out of the village. Suggestions regarding the utilization and diffusion of AD elsewhere are presented to enhance the potential capacity of the practice to generate benefits across rural Hainan.

Keywords Anaerobic digestion · Biogas · Community development · Public participation · Sustainability

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Introduction

Ever since the concept of sustainable development entered common discourse in 1980 (IUCN, UNEP, & WWF, 1980), sustainable development in undeveloped rural areas has been promoted worldwide as a long-term goal by most decision makers to overcome problems and constraints that confront the economic viability, environmental soundness and social acceptance of agricultural production systems (Lockeretz, 1988). In order to achieve the development "*that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987, p.43) in developing rural areas, the Food and Agricultural Organization [FAO] of the United Nations has extended the definition by emphasizing the importance of local natural resources and the roles of technological changes in the process of development in developing rural areas (Anon, 1989). According to FAO (Anon, 1989), the definition of '*sustainable rural development*' is,

> "the management and conservation of the natural resources base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development in the agriculture, forestry and fisheries sectors conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable." (p. 1)

A particular resonance of sustainable development has been recognized in rural settings to emphasize forms of conservation, production and development practice that are more 'endogenous' or 'integrated' in their orientation than those which have prevailed in the past to provide farmers with economically viable options for their farming systems (Bowler & Lewis, 1991; Keane, 1990; Van der Ploeg & Long, 1994; Virmani, Katyal, Eswaran, & Abrol, 1994). Among many sound practices around the world, anaerobic digestion (AD) has received significant attention since the energy crisis in 1970s (Ni & Nyns, 1996), especially in developing rural areas where the technology has been connected with sustainable development initiatives, resource conservation efforts, and regional development strategies (Wang & Li, 2005). Ramachandra, Joshi, and Subramanian (2000) have observed that,

> "The scarcity of biofuels has far reaching implications on the environment. Hence, expansion of bioenergy systems could be influential in bettering both the socio-economic condition and the environment of the region" (p. 375).

Household-based application is one of a number of village-scale rural practices which offer the technical possibility of more decentralized approaches to community development (Akinbami et al., 2001). In terms of installed numbers of units and years of use AD technology represents one of the most mature rural technologies (Hall, 1993), and is currently in vogue among governments and aid agencies in many developing countries such as India, China, the Philippines and Turkey (Akinbami et al., 2001; Ni & Nyns, 1996).

The technology is based on the biodegradation of organic matter in the absence of air (anaerobically), and results in the formation of biogas which typically contains methane (ca. 60–70%), carbon dioxide, and various trace gases, some of which may be highly odorous and/or corrosive (Barnett, Pyle, & Subramanian, 1978; Duggal, Vyas, & Sandhar, 1987). Anaerobic treatment processes are especially well suited for the utilization of wet organic wastes from agriculture and industry as well as for the organic part of source-separated household wastes (Weiland, 2000). Common feedstock of AD includes animal dung, household wastes, and crop residues (Akinbami et al., 2001). Shah (1997) notes that there may be an increase in the quantity of biogas produced from a particular waste when it is mixed with other wastes. Biogas can be substituted for traditional fossil-based fuels (Ramachandra et al., 2000). Typically, 1 m^3 of biogas contains approximately 21 MJ energy, equal to 2.04 kWh electricity (35% ŋ) or 2.33 kWh thermal energy (40% ŋ) (Murphy, McKeogh, & Kiely, 2004).

Although AD is merely a technology, the implementation of the technology requires more than technical considerations. Moawad, Zohdy, Badr, Khalafallah, and Abdel (1986) identify that the implementation of AD technology is an integrated sequence of processes, including waste management, digestion, and effluent and gas handling and usage. Successful development and management of AD technology require not only technical expertise but serious attention to economic and social issues, as well as human behaviours (Ni & Nyns, 1996). The impacts and benefits of AD technology for developing countries have been discussed to some extent in the literature (Ni & Nyns, 1996; Wang & Li, 2005; etc.). However, most research on AD technology has focused on exploring the theoretical impacts and benefits of the technology. Specifically, as Wang and Li (2005) have identified, very few practical surveys have been conducted among individual families in rural areas. Given this gap, the assessment of the impacts of AD technology on a household basis at specific destinations in developing rural areas is needed.

Study objectives

The central purpose of this study is to assess, using the ''*diffusion-operation-impacts*'' paradigm, the current status of AD practice on a household basis in a village to find out how the technology is diffused and operated towards sustainable rural development or how the technology strengthens rural sustainability. In order to identify strategies in the village, we examined: (1) the economic basis of the study site; (2) stakeholders' roles in AD technology diffusion and utilization; (3) household demographic, livestock and agricultural information; (4) public perceptions towards AD technology in relation to local residents and the community; (5) impacts of AD technology on the village; and (6) possible problems or obstacles of technology diffusion.

The study focuses on the existing AD practice on a household basis in Meiwan Xincun Village (MWXCV) in Hainan Province, China. Exploratory in nature, the study is intended to identify key factors that ensure the success of the practice in the village and may be applied elsewhere in the developing rural areas of Hainan. Lessons learned from the village should be significant for the introduction and diffusion of AD technology for villages and destinations elsewhere. Policy implications from the study will possibly provide planning directions for the Provincial Government of Hainan to promote sound technologies throughout developing rural areas.

Study site description

Separated from Guangdong Province of Mainland China by the 24-km wide Qiongzhong Strait, Hainan Province is located in the South China Sea which is the southernmost part of China (Fig. 1). With a total area of 34,000 km^2, Hainan Island is the smallest land province and the largest sea province of China (Hainan Provincial Tourism Bureau [HPTB], 2003). Located at 18°10–20°10 North Latitude, Hainan has a marine tropical monsoon climate with an annual average temperature ranging from 22.4–25.5°C and yearly average rainfall of 1,500–2,000 mm, very suitable for tropical agriculture (Hainan Department of Land Environment and Resources [HLER], 1999). With ambient temperatures in the 20–40°C range, AD systems are expected to operate successfully on the island (Han, 1997).

With a population of more than seven million, Hainan is the largest Special Economic Zone (SEZ[1]) in China. Unlike other SEZs, Hainan is still dominantly rural and more than 80% of its population are farmers (Han, 1997). Consequently,

Fig. 1 Hainan and Meiwan Xincun Village (MWXCV) adapted from: http://encarta.msn.com/map_701512910/Hainan.html

[1] A Special Economic Zone is a region that has economic laws different from a country's typical economic laws. Usually the goal is to increase foreign investment, introduce advanced technologies and create job opportunities. There are five SEZs in China—Shenzhen, Zhuhai and Shantou in Guangdong Province, Xiamen in Fujian Province, and Hainan Province (He, 2001).

agriculture has a dominant role in the local economic development of Hainan. The economic development history of Hainan, to some extent, is the history of agricultural development (Xia & Li, 1994). Unfortunately, parallel with the pursuit of economic development, widespread environmental damage has occurred on the island, although not as severe as that in mainland China. The main environmental problems in Hainan include the death of large amounts of coral, the loss of mangrove areas, and decreased forest coverage caused by deforestation (Zhao, Liu, & Lin, 1999). The largest cause of the environmental problems is that most rural people in Hainan rely on biomass as their major source of fuel and associated deforestation-based energy consumption has exceeded the regenerative capacity of the natural resources (HLER, 1999).

In order to take an integrated approach to resource management, the provincial government has formulated an ‘‘*Eco-Province Strategy*’’, aiming at building Hainan as the first ‘‘Eco-Province’’ in China (HLER, 1999). Since Hainan is a developing and rural dominated area, the key to the success of the strategy is to promote rural sustainability. Consequently, the provincial government is trying to implement the strategy in the rural areas by turning the natural villages into ‘‘*Civilized and Ecological Villages*’’. The ‘‘*Eco-village*’’ Plan is intended to help the rural people across the island, (1) improve the rural environment; (2) develop the rural economy; and (3) create an ecological culture (Hainan Civilization-Ecology Office [HCEO], 2002). Meiwan Xincun Village (MWXCV) in Danzhou is one of the eco-villages supported by the government.

MWXCV is located in the mountainous and largely undeveloped northwest part of Hainan. The village has a total land area of approximately 700 ha and a 100 ha reservoir. Almost 85% of the land area is forested. A population of 243 occupied 52 households in the village in 2003. With technical support from the Chinese Tropical Agricultural Academy, the agricultural resources in the village are reasonably utilized. The main agricultural products in the village include natural rubber, tropical fruits (lichee and oranges), and rice. All the households in the village are involved in livestock raising. The main animals include pigs, buffalo, chicken, ducks, and dogs. Under guidance from the Danzhou Biogas Station, all households in the village have installed biogas digesters. Some of the households also have installed domestic solar water heaters and solar photovoltaic equipment. With the improvement of the rural environment and infrastructure, the villagers have identified rural tourism as a new economic growth point in the village.

Methods

A case study approach was employed to investigate people’s perceptions and the impacts of the household anaerobic digesters in MWXCV. A mix of inter-related qualitative and quantitative methods was used. To explore the people–digester–community relationships in the village, purposive sampling strategies were adopted and data from various stakeholders related to anaerobic digesters, including government officials, local experts, leaders of the village, and local residents, were collected. A self-administered questionnaire survey was carried out among the local residents on a household basis. For the purposes of cross-checking and complementing primary data, secondary data were also collected through a literature review. The qualitative methods were on-site observation; face-to-face interviews with the government officials, local experts and leaders of the village to address the scope, scale and character of the scheme; and semi-structured interviews with local villagers. Where direct quotations are given in the text, they are drawn from the interviews and discussions, unless indicated otherwise. The field research was conducted between May and August, 2003.

Questionnaires were designed to investigate AD practice, waste management styles, stockbreeding raising styles, and economic conditions, as well as public perceptions and environmental awareness in MWXCV. The community residents were accessed under the guidance of the village leaders. The respondents were adults knowledgeable about their family situation, especially AD practice in their households. Of the 52 surveys sent, 45 or 87% were completed and returned. For the questionnaire survey completed among the local residents, responses were coded and then the data were analyzed and presented in terms of descriptive statistics (frequency, percentage, maximum, minimum and mean) based on the use of SPSS.

Pigs, chickens and dogs were the common animals raised by all 45 households (respectively by 89, 80 and 24% of the 45 households). The educational levels of the majority of the respondents are low. Some 51% of them have a primary and 27% have a secondary level of education. All the respondents have adopted AD into their households and 89% of the respondents have utilized additional sources of renewable energy (Table 1). Average household size was four to five individuals and each had around five pigs, six dogs and three dozens of chicken (Table 2).

The process of interviewee recruitment was largely based on a snowball approach. With the assistance of the Hainan Department of Land, Environment and Resources (HLER[2]), a list of government officials from the environmental department and

Table 1 Community respondents and household information

Indicators	Residents Percentage (N = 45)					
Educational level	Primary	Secondary	High school	Collegiate or above		
	51	27	18	4		
Livestock Raising	Yes	No				
	100	0				
	Pigs	Chickens	Dogs	Cattle	Geese	Sheep
	89	80	24	4	4	2
Using digester	Yes	No				
	100	0				
Year adopting	1992	1993	1996	2000	2001	2002
	2	2	7	18	67	4
Volume of digester	6 m^3		8 m^3			
	96		4			
Utilizing other sources of renewable energy	Yes	No				
	89	11				
	Solar water heater		*Photovoltaic cells*			
	64		78			

[2] The department is a participant of the EcoPlan-China Project, based in the Faculty of Environmental Studies, University of Waterloo, and aims at helping China's coastal regions (including economic development zones) to establish sound human capital and institutional capacities to design, implement and monitor integrated environmental policies and programs.

Table 2 Relative information about anaerobic digesters in MWXCV

Indicators	Minimum	Maximum	Mean
Number of people in household	3	8	4.5
Household income in 2002 (RMB Yuan)	18,000	100,000	32,933
Livestock raising at home (main animals)			
Number of pigs	2	12	5
Number of chicken	2	98	32
Number of dogs	2	12	6
Anaerobic digester costs			
Building cost (RMB Yuan)	1,000	1,300	1,258
Governmental support (RMB Yuan)	300	800	400
Other support (RMB Yuan)	120	400	200

agricultural department, both at the provincial and local levels, was developed in order to gather contextual and supporting information. In total, seven government officials were interviewed. Based on the interviewees' knowledge, six local experts on anaerobic digesters in Danzhou and five leaders in MWXCV were suggested as key informants to explain or set the context for AD development in the community. Finally, four local experts and five leaders were interviewed. Structured interview guides were provided to the interviewees in advance. Topics generally centred around AD in Hainan, rural economy and environment, and other planning and management issues. During the interviews, notes were taken and the interviews were audiotaped with permission. After each interview, the audiotaped record was transcribed. Considering the diversity of interests that exist in the village, methodological and data triangulation[3] related to the interview results was employed through on-site observation, informal interviews with local residents and cross-checking with the results of questionnaire survey to limit individual and methodological biases.

Anaerobic digestion in MWXCV

The current applications of AD technology are generally successful in MWXCV. Some findings of public environmental awareness and information of AD have been provided in Table 3.

Before AD was introduced in the village, firewood from a nearby forest had been the main source of energy in the village. The male residents used to spend five to six hours every week obtaining firewood mainly by manual deforestation to meet the energy needs of each family. One hundred percent of the households in the village depended on fuelwood to meet their energy needs before biogas replaced fuelwood. One recent experiment (Boy, Bruce, Smith, & Hernandez, 2000) was carried out in rural Guatemala and examined the daily household firewood consumption which

[3] Originated from geometric calculation in a triangle, the approach was first introduced into social research in 1960s (Webb, Campbell, Schwartz, & Sechcrest, 1966), and evolved into four approaches—methodological, data, investigator and multiple triangulations (Denzin, 1978). In order to avoid biases, the approach requires measures to be interrelated besides the premise that each measure is right. Methodological triangulation refers to using more than one research method to examine a same question. Data triangulation means to use same approach for different sets of data in order to verify or falsify trends generalized in one data set. Investigator triangulation refers to making use of different investigators with different background. Multiple triangulation combines at least two of the other triangulation methods in combination (Oppermann, 2000).

Table 3 Selected questionnaire survey responses at MWXCV

Survey question	Responses	Community residents # of responses	Community residents % of responses
How do you evaluate the local environment?	Very good	35	78
	Good	8	18
	Poor	2	4
Is protecting rural environment/resources important to you? If yes, why?	Yes	45	100
	Nature/Agriculture	42	93
	Quality of life	30	67
	Water resources	12	27
	Climate	9	20
	Well-being of children	18	40
What was the main source(s) of energy before adopting a digester?	Firewood	45	100
	Agricultural wastes	42	93
	Gas	27	60
	Coal	1	2
What is the main feedstock of the anaerobic digester in your home?	Human manure	42	93
	Livestock manure	45	100
	Agricultural wastes	41	91
What is the main usage of biogas?	Waste water	8	18
	Cooking	45	100
Is biogas generated from the digester enough for your daily cooking needs?	Yes, with surplus	29	64
	Yes, without surplus	16	36
	No	0	0
What is the main usage of the sludge of the digester?	Natural fertilizer	45	100
	Livestock foodstuff	3	7
	Composting	2	4
Has AD technology impacted your livelihood in a positive and/or negative way? Can you provide specific examples?			
Positive livelihood effects cited	Energy	45	100
	Economy	36	80
	Environment	35	78
	Fertilizer	32	71
	Health/well being	21	47
	Development	12	27
Negative livelihood effects cited	N/A		
Within next ten years, will you make use of or continue to use anaerobic digester or other sources of renewable energy?	Yes	45	100

was calculated as firewood consumed per "adult male equivalent" (AME[4]). The result shows that an adult male needs to consume 1.93 ± 0.818 kg firewood everyday to meet the daily energy needs for cooking in developing rural areas. Experts from Danzhou Biogas Station estimated that 10 kg of firewood needed to be burned for each household in the village to meet the energy needs of cooking everyday (interview, 2003). If deforestation took place in the same rate, as conservatively estimated by the director of the village, the forest around MWXCV would disappear within 100 years. While agricultural wastes in the village were used as foodstuffs for the animals, a small proportion was used to supplement the energy needs before AD

[4] Originally, the method involves taking the adult male food consumption rate as a reference, and assumes that other family members including women, children, elderly persons, consume less which are calculated according to specific ratios (Baldwin, 1986).

in the village. Prior to AD, the sanitary system in the village was poor and no formal animal enclosures had been built. Human manure was utilized as nightsoil for agricultural irrigation purposes. A small proportion (10% as estimated by the village leaders) of animal manure had been collected, dried and burned to meet energy needs, while most of the manure remained scattered and unutilized in the village. Not all animals were raised within enclosures.

The typical volume of anaerobic digester is 6 m^3. Each digester is located in the backyard and occupies an area about 14 m^2. Digesters are constructed of concrete and connect with the household toilets and livestock enclosure, allowing both human and animal manure to flow automatically into the digesters. Agricultural straw is also often utilized as feedstock. The digester is connected with a stove by a plastic pipeline. Before the biogas can be used, 90% of the hydrogen sulphide (H_2S) is removed by a deodorizing machine which is manufactured by Energy Saving Apparatus and Instrument Factory of Jiangxi Province [ESAIFJP] (ESAIFJP, 2004). A barometer is installed in the AD system to indicate available biogas pressure which for cooking purposes should be between 4 and 6 pounds. Excess slurry from the digester has to be removed whenever pressures exceed 8 pounds. Otherwise, efficiency of AD is decreased. Using a metal pot, local residents remove the slurry by a metal pot once a week and store it in a 1 m^3 cement container in the backyard. The slurry is carried in a bucket and spread onto the farmland, vegetable and fruit gardens (Fig. 2).

Over 80% of the informants regarded AD technology as a good thing and would welcome more sound technologies. The overwhelming attitude towards introducing AD technology widely in developing rural areas across the province was optimism, with most officials, experts, leaders and local residents seeming confident that the technology would generate benefits.

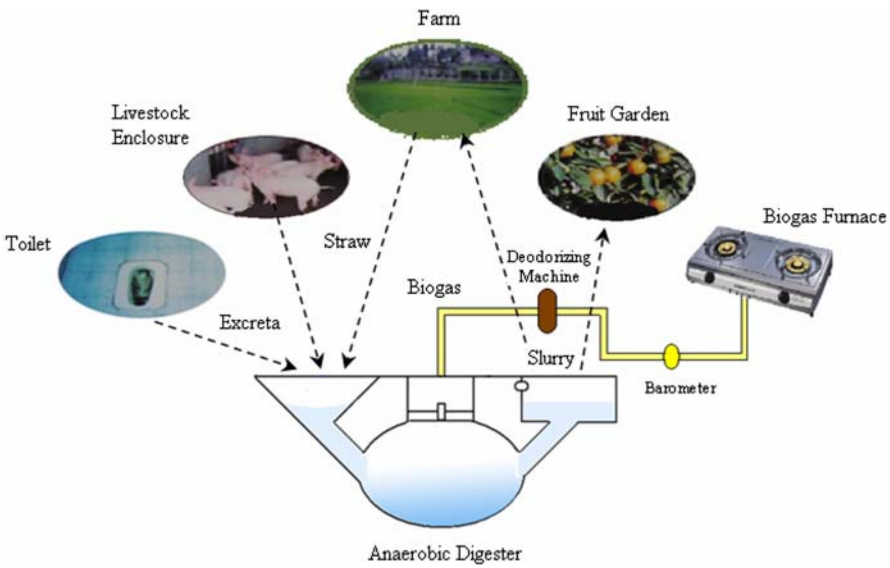


Fig. 2 Anaerobic digestion system in MWXCV

The process of technology diffusion

The leaders and the villagers agreed that the largest proportion of energy was consumed by cooking. Like most rural people across Hainan, the majority of villagers had relied heavily on biomass to meet their energy needs before AD and solar energy technologies were introduced into the village in the early 1990s. All informants noted that the cooking energy demand in the village was met mainly with continuous use of firewood, leaves, twigs, agro-residues and animal manure. Explanations of the reliance on biomass varied from inheriting a tradition to economic considerations, with more referring to the nature of biomass—free or cheap to use. Realizing the potential energy crisis existing in the village and nearby, the leaders set out to seek economically feasible and environmentally viable alternatives to meet the energy needs in late 1980s. With the recognition of the significance of protecting rural environment and natural resources in relation to local agriculture development, they tended to focus on the energy-oriented local disadvantages which needed to be overcome. Under the technical assistance from the Danzhou Biogas Station, the leaders of the village acted as pioneers in adopting anaerobic digesters. Later, they acted as technology extensionists to publicize the technologies throughout the village.

The diffusion process of a small-scale rural technology contains two stages—introduction of the practice and integration into a user's livelihood. If AD technology is to be diffused, public acceptance and participation in the project become key steps (Bi and Haight, 2004). The experts from Danzhou Biogas Station have affirmed that the same challenges of acceptance and participation exist in other villages. As a matter of fact, although the village leaders had devoted time to introducing AD technology to the villagers, provided them with information about the reasons behind adopting digesters and explained the importance of protecting the natural resources, the majority of residents, before 2000, did not accept the technology as it was against their traditional lifestyles.

The village leaders and the experts from Danzhou Biogas Station attributed the difficulty in the technology introduction process to the limited education among the villagers, 78% of which had education no higher than equivalent secondary school. They further identified the poor economic conditions as the main obstacle impeding technology diffusion. Gustavsson (2000) asserts that certain economic conditions have to be met for the diffusion of small-scale rural technologies, but that poor economic conditions will not prevent an introduction. The tropical agriculture economy in MWXCV has grown continually and the average annual family income increased from 11,367 RMB Yuan in 1990 to 32,933 RMB Yuan in 2002 (Fig. 3), which represents a remarkable achievement in Chinese rural economic development. Ninety one percent of the households responded that the living standard in the family had improved compared to 10 years ago. The majority of the households expressed satisfaction with current life and 78% indicated that in recent years the family income was enough to meet basic daily consumption needs, e.g., food, clothing, tuition of the children, agricultural expenses, and they often had surplus money to spend on other things.

While villagers installed digesters slowly, it was not until 2000 when the provincial government of Hainan became actively involved by providing financial incentives and compensation that adoption of AD started to accelerate. With the governmental

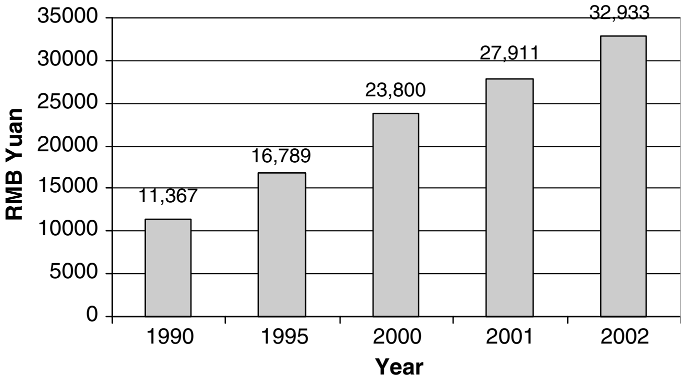


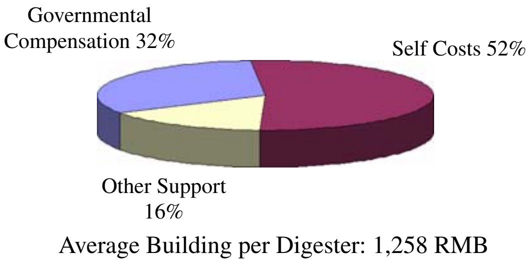
Fig. 3 Average annual family income in MWXCV

financial incentives, the economic burden of the villagers was greatly alleviated and thus stimulated the diffusion process. All 52 households have digesters and at least 40 were installed between 2000 and 2002.

Allocation of the governmental financial support was largely tied to completion of the rural environmental rehabilitation activities and a good-working condition of the equipment. Villagers were encouraged to provide the labour and cover the costs themselves. They bought materials in the technical equipment market of Heqing Town, installed the equipment and built the anaerobic digesters under the guidance of the experts from the local research institutions, such as the Danzhou Biogas Station, the Danzhou Environmental Supervising Station and the Chinese Tropical Agriculture Academy. Once completed, the project was inspected and approved by the experts before financial compensation was given. The amount of compensation varied, since the compensation policy was based on the economic conditions. The five pioneering projects which had been completed before 1997 were not compensated as the compensation policy on AD had not been implemented. The forty digesters installed between 2000 and 2002 were compensated and the amount ranged from 300 RMB Yuan to 800 RMB Yuan, with an average of 400 RMB Yuan. Additionally, 89% of those surveyed explained that they had obtained some financial support from other sources, including the village endowment fund, non-governmental support and their out-of-village or overseas relatives. Because of governmental compensation and financial support from other sources, the average costs of a biogas reactor for a household went from an initial investment of 1,258 RMB Yuan to 658 RMB Yuan (Fig. 4). Governmental financial incentives and other sources of financial support (e.g. financial support from out-of-village relatives with better economic conditions) helped to alleviate the economic burden of the villagers in MWXCV and thus helped to promote the introduction and adoption of AD technology throughout the village and even into the surrounding rural areas.

During the process of AD technology diffusion in MWXCV, the provincial government, local research institutions, the leaders and the villagers have participated. The leaders' diligent introducing, publicizing and communicating provided the basis for the dissemination. With the technical support from local research institutions and the financial incentives from the government, the diffusion process was greatly facilitated. Although educational levels of the villagers were low, they

Fig. 4 The digester cost pattern in MWXCV



began to accept the technology after they recognized the potential benefits of the technology through learning from the leaders' introduction and the peers' experiences. The villagers' co-operation and participation were at once willing and voluntary with whatever possible within their means and capacities under the governmental financial incentive programs. The majority of the villagers said they would like to input labour and invest in small-scale rural technologies within their affordability.

Current operation of anaerobic digesters in MWXCV

Since 1996, the application of AD has extended beyond merely providing biogas. Current AD practices have been integrated into the residents' livelihood system and agricultural practices (Fig. 5). The 45 respondents who completed the survey have combined recycling, utilization of energy together, with providing a supply of organic fertilizer.

These practices make use of something that otherwise was to be wasted, or at least being underutilized. The main feedstock of anaerobic digesters includes human and livestock wastes, waste water, and agricultural wastes, such as straw and crop residues. One hundred percent of the households have affirmed that the human, animal manure and waste water generated everyday flow into the digesters and 67% of the households input straw and crop residues into the anaerobic digesters, and 4% of the households compost the surplus agricultural wastes and then use the compost as organic fertilizer on the farm.

While biogas is utilized mainly for cooking, the Director of the Danzhou Biogas Station explained that biogas is also utilized for light especially in households situated in remote mountainous rural areas of Danzhou where there is no electricity or people are too poor to purchase electricity. While biogas has become the main source of energy, it was noteworthy that 60% of the households have bought liquefied gas at an average monthly cost of 55 RMB Yuan. Sixty four percent of the households indicated that the biogas they produced satisfied their daily cooking needs with surplus, and 36% of the households responded "satisfied but no surplus". Users declared that the liquefied gas equipment was available in case the biogas was not sufficient for daily cooking or important occasions, such as village reunions, festivals and marriages, when even extra energy was needed.

Although the biogas is easy, convenient and efficient to use, not all adopters were confident enough to use biogas soon after the digesters had been put into use. A majority of the households stated they were not accustomed to using the new energy

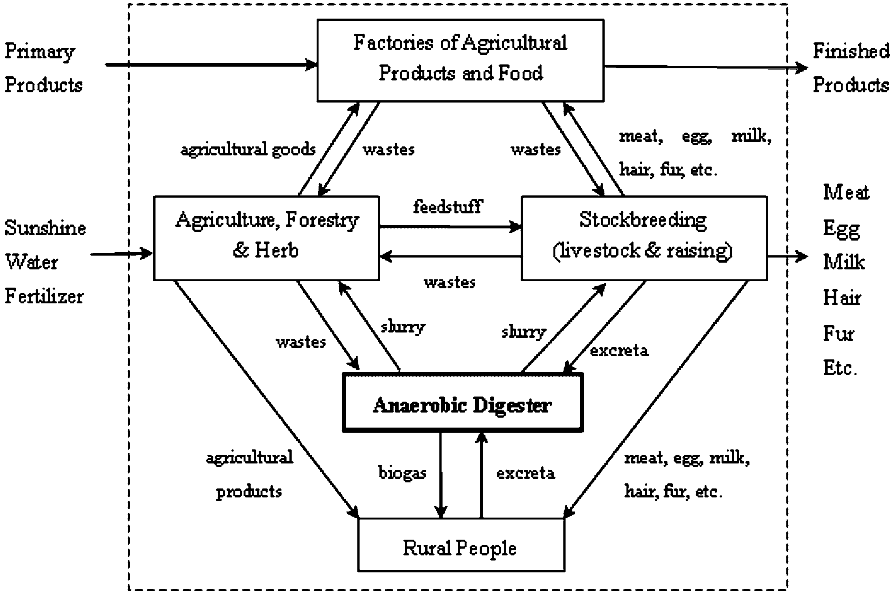


Fig. 5 Anaerobic digester incorporated into the livelihood system in MWXCV

for cooking at the very beginning, while a large proportion (73%) of the respondents were afraid of a biogas-related explosion. One government official indicated that early fear is one of the major mental barriers of the rural people to adopt anaerobic digesters. In addition to this, current training programs on scientific and proper use of anaerobic digesters are limited. Experts interviewed also emphasized the creation of the accompanying hydrogen sulphide (H_2S) in a digester, which corrodes cooking equipment, and harms human health if not removed. A deodorizing machine is installed in the biogas system to filter biogas. The main chemical components of the machine are Fe_2O_3 and Fe_3O_4 and according to the manufacturer, 90% of the hydrogen sulphide in biogas can be removed by the deodorizing machine (ESAIFJP, 2004). In order to maintain the effectiveness of the deodorizing machine, the deodorizing machines in MWXCV are washed and dried every four months and replaced once a year. The costs of a new device are around 80 RMB Yuan, including 30 RMB Yuan for the machine and 50 RMB Yuan for the ferric oxide (interview, 2003). With careful practice, all the villagers now accept and continue to show confidence about using biogas. The majority of households understand that a biogas digester is safe to use if it is used and managed properly. The director of the village affirmed that there have been no accidents caused by anaerobic digesters.

The fermented slurry is removed based on the biogas pressure as shown in a barometer. A high biogas pressure which typically exceeds eight pounds indicates the storage space for biogas in the digester is insufficient and some of the slurry should be removed. Removed slurry has many applications in agricultural practices and livestock raising. The conversion to energy through biogas production does not greatly reduce the value of the slurry as a fertilizer (Fischer & Ianotti, 1977). The fermented slurry, rich in nitrogen and humus, forms a good organic manure which can be applied directly to agricultural fields (Biswas and Lucas, 1997). All the households applied the fermented slurry to agricultural farmland, vegetable gardens and fruit gardens and a few processed the slurry into animal foodstuff for pigs and fish raising. Only 2% of the households recycled the slurry by putting the slurry back into digester for re-fermentation.

Adopting an AD practice leads to changes as summarized:

- encourages low dependence on natural resources to meet local energy needs;
- works within a closed recycling system with regard to organic mater and nutrient elements;
- makes use of something that is otherwise going to be ‘‘wasted’’ or at least is being underutilized;
- provides efficient energy and fertilizer produced though natural chemical reactions;
- avoids pollution within the rural livelihood system;
- allows adequate agricultural and commercial returns as well as life satisfaction for rural people;
- enhances local environmental awareness.

Resulting impacts of anaerobic digestion in MWXCV

The resulting impacts of AD practice in MWXCV can be classified into six categories, including energy-related, fertilizer-related, economic-related, health-related, environment-related, and development-related benefits.

Energy-related benefits

In rural areas, the advantage of biogas can be seen especially from the replacement of an inefficient but traditional fuel with a more efficient and flexible one (Kaale, 1990). AD technology can help rural people meet their fuel needs by the reliable energy secure means in developing rural areas (Akinbami et al., 2001). A 6 m^3 anaerobic digester in MWXCV has an annual net energy output of 3.5 million kcal (Table 4).

The AD practice has eradicated the villagers’ reliance on fuelwood which was obtained mainly by deforestation. The importance of the forest resource to the local environment is generally accepted by most residents. Some residents even noted that they benefited from the practice in terms of the time saved from daily collection of fuelwood, animal waste and crop residues. However, it could not be ignored that all respondents had planned to continue relying on fuelwood to meet their energy needs if they had not adopted anaerobic digesters. One governmental official explained the situation by referring to the direct correlation between poverty and resource exploitation in developing rural areas. This relationship suggests that the attempt to prevent deforestation through education or regulation will not be effective until the energy security problem is resolved first.

Fertilizer-related benefits

The digestion slurry and solids contain 30–50% organic matters, 10–20% humus, 75.8 mg/l of nitrogen, 2.0 mg/l of phosphorus, 66.6 mg/l of potassium, and various microelements (Ka & Lu, 2000) making the ‘wastes’ of anaerobic digestion a good

Table 4 Annual inputs and outputs of a 6 m^3 anaerobic digester in MWXCV

	Quantity	Kcal (10^3)
Input		
Human manure	2,700 kg[a]	–
Livestock manure	5,100 kg[b]	–
Agricultural wastes	600 kg[c]	–
Man-hours	236 h[d]	–
Initial investment (digester with 30-year life)	42 RMB Yuan[e]	–
Costs for equipment replacement[f]	80 RMB Yuan	–
Concrete[g]	168 kg[h]	315[i]
Steel (digester and other equipment with 30-year life)	0.33 kg[j]	0.69[k]
Steel truck/tractor[l] for transportation (10-year life)	10 kg	200[k]
Petroleum for transport[l] (10 km radius)	34 l	340[m]
Total input		856
Total output[n]		4,380

[a] A mature person produces about 600 kg of manure annually (Gansu Agriculture Department [GSAD], 2004). The total amount of human manure processed is estimated by multiplying this number by 4.5 which is the average number of persons

[b] A pig (40–50 kg) produces 2.0–2.5 kg of organic matter everyday (GSAD, 2004). The average number of pigs in each household is 5. Given the diversity of livestock being raised by each family, the authors conservatively estimate livestock manure processed in a digester at 5,100 kg per year

[c] Estimated by biogas specialist from Danzhou Biogas Station (Interview, 2003)

[d] See Table 6

[e] The average initial costs for an anaerobic digester in MWXCV was 1,258 RMB Yuan. When this amount is divided by 30, the annual initial investment is 42 RMB Yuan

[f] Including 30 RMB Yuan for the machine and 50 RMB Yuan for the ferric oxide

[g] Weight ratio of cement/sand/gravel/water is 1:1.9:4.9:0.6

[h] Concrete needed to built a 6 m^3 digester is about 5040 kg (Chen, 2000). One thirtieth is about 168 kg

[i] Slesser and Lewis, 1979

[j] Total steel needed is about 10 kg (Chen, 2000). One thirtieth is about 0.33 kg

[k] 1 kg of steel = 20,700 kcal for mining, production, and transport (Pimentel, et al. 1973)

[l] Estimated

[m] A litre of fuel is assumed to contain 10,000 kcal. Included in this figure are mining, refining, and transportation costs (Pimentel, et al. 1988)

[n] A 6 m^3 anaerobic digester has a capacity to yield 876 m^3 biogas and 1 m^3 biogas contains 5000 kcal (Chen, 2000)

source of natural fertilizer. Agricultural yields have the potential to increase by 6–20% (Marchaim, 1992). Some 98% of the respondents in MWXCV reported that they have reduced using chemical fertilizers in their agricultural practices under the guidance of experts from Danzhou Biogas Station. This reduction did not often result in diminished agricultural yields. Although increases where not always reported by, some residents did acknowledge the positive benefits of the digestion slurry in terms of supplying plant nutrients, improving soil aggregation, increasing water-holding capacity of the soil, stabilizing the humid content and prevention from leaching of nutrients. Results of recent experiments carried out by Danzhou Biogas Station in 2000 affirm that there are significant increases of organic matters in the soil as well as the yields of main agricultural products (natural rubber, rice and vegetables) of the village as a result of applying digestion slurry in agriculture (Table 5).

Economic-related benefits

In terms of economic benefits, there are monetary savings. While most residents affirmed the economic benefits of AD technology in terms of savings of labour input (Table 6) and expenses on energy and chemical fertilizers, the economic viability cannot be ignored (Biswas & Lucas, 1997). The AD experience indicates that although local residents need to pay for the digester, the economic viability of the technology can be satisfied when appropriate monetary incentives are provided. With an annual investment of about 122 RMB Yuan (Table 4) and labour input of about 236 man-hours (Table 6), villagers are able to run and maintain an anaerobic digester in their households. In other words, the cost and labour input per cubic meter of biogas are 0.14 RMB Yuan and 0.27 man-hours.

Table 5 Summary of experiments of digestion slurry in agriculture by Danzhou biogas station

Subject	Comparison	Results
Effects on soil quality	Condition 1: Applying digestion slurry to 1 hectare farmland around 2,000 kg/year for three consecutive years	•The contents of organic matter in the soil after using digestion slurry increased about 30%
	Condition 2: Using chemical fertilizers only without digestion slurry	•The density, rift, temperature and water-holding capacity of the soil after using digestion slurry improved
Effects on natural rubber yield	Condition 1: Applying 1,500 kg digestion slurry, 15 kg carbamide and 30 kg compound chemical fertilizers to one fifteenth hectare of rubber farm land	• The yield of dry natural rubber was 94.8 kg in condition 1—a 17% increase compared to condition 2
	Condition 2: Applying 50 kg carbamide and 100 kg compound chemical fertilizers in one fifteenth hectare of rubber farm land	• A net income increase per hectare of 135 RMB Yuan in condition 1 as a result of increased yield of natural rubber and reduced costs for chemical fertilizers
Effects on rice yield	Condition 1: Applying 900 kg digestion slurry, carbamide 6 kg to one fifteenth hectare of rice land Condition 2: Applying 26 kg carbamide and 25 kg phosphorus fertilizer to one fifteenth hectare of rice land	• The yield of rice in condition 1 was 472.7 kg—a 12% increase compared to condition 2 • Comparing more labour in condition 1 against more costs for chemical fertilizers in condition 2, condition 1 saved 10.5 RMB Yuan • A net income increase per hectare of 13.6% in condition 1 as an effect of increased yield of rice and reduced costs of chemical fertilizers
Effects on vegetable yield	Condition 1: Applying digestion slurry with chemical fertilizers	• The yields of vegetables in condition 1 were 20% greater than those in condition 2
	Condition 2: Applying chemical fertilizers only	• Vegetables in condition 1 have better texture and are more resistant to rotting

Source: Chen, 2000

Table 6 Labour input before and after anaerobic digestion (man-hours)[5]

Before anaerobic digestion			Anaerobic digestion (digester with 30-year life)		
	Weekly	Yearly		Weekly	Yearly
Chopping trees for firewood	5.5	286	Initial labour input[6]	–	2
Collecting other sources of fuel	2.5	130	Inputting manure & agricultural wastes	0.5	26
Collecting agricultural wastes	2.5	130	Getting slurry out	1	52
Collecting livestock manure	3.5	182	Equipment inspection & replacement	0.5	26
Making fire ready for cooking	4.5	234	Collecting agricultural wastes	2.5	130
Total		962	Total		236

Initial investment and labour input should not be excuses to refuse anaerobic digesters. On the other hand, financial compensation for digester adopters is strategically important as poverty can be a stumbling block for the introduction and diffusion of small-scale rural technologies. With the economic burden being alleviated by way of governmental initiatives and other support, the diffusion of anaerobic digesters in the village was quite successful and villagers regarded the short-term investment as appropriate.

Health-related benefits

Much smoke is created from burning traditional fuels such as fulewood, animal dung and crop residues. The smoke contains damaging pollutants, which may lead to severe illness, including pneumonia, cancer, and lung and heart diseases (Smith, 1993). Biogas is clean and efficient with carbon dioxide and water as the final products of combustion. The shift from the traditional fuels to biogas reduces people's exposure to thick smoke and the susceptibility to the lung diseases. All the residents surveyed affirmed improvements of their health through improving the indoor environment of kitchens and eliminating the smoke when cooking. A technical expert also noted the health-related benefits of AD in terms of reducing the breeding of vermin, such as mosquitoes, flies and harmful germs, and the broadcast of pathogens in the village.

Environment-related benefits

AD technology provides safe and clean disposal of human and animal manure and agricultural wastes. Since toilets and animal enclosures were connected to the digesters at a household scale, positive waste management has become a spontaneous behaviour in MWXCV. The rural living environment has greatly improved, mainly as a result of the shift to a more positive set of waste management practices. As fuelwood is no longer the main source of energy in the village, the forest resources also are well preserved. With recent effort, forest coverage in the village has reached 85%, which contributes to maintaining water and soil fertility,

[5] All data of labour input are averages from the questionnaire survey in 2003

[6] Initial labour input for a 6 m^3 anaerobic digester is 60 man-hours. One thirtieth is 2 h.

protecting wild species, cleaning air and reducing noise (He, Jing, & Wang, 1992). While all officials and technical experts interviewed agreed that the rural environment is very good, 87% of the residents declared that the environment of MWXCV has improved compared to 10 years ago. Both leaders and residents of the village are optimistic about long-term improvement in rural environmental quality.

Development-related benefits

Rather than pursuing merely growth-based development, people should have a more ecological understanding of environmental limits (Mitchell, 2002). With AD technology incorporating the rural livelihood system in MWXCV, the mode of economic development in the village has shifted from a process of exploiting resources to a more environmentally responsible one. A common goal is to pursue a ''*commonwealth of values*'' at the intersection of environmental, economic and social aspects to achieve conservation with equity, environment-economy integration and community economics as if people mattered (Saddler, 1990). Combined with the energy, fertilizer, economic, health and environment-related benefits, the AD practice in MWXCV allows local residents to pursue economic development without sacrificing the rural environment and resources. The strength of the practice lies in its capacity to facilitate the interdependence of economic well-being and environment management, making the practice an effective means towards sustainable rural development.

Conclusions

The broad overview of the AD practice in MWXCV in terms of technology diffusion, current operation and local impacts has identified a number of important opportunities and obstacles for the future AD development in MWXCV as well as for other communities in rural Hainan. In order to achieve a satisfying diffusion of the technology, all stakeholders, including local residents, village leaders, technical specialists and government should participate actively throughout the process. Financial incentives from the government are strategically important in the technology diffusion process, as financial assistance can stimulate the adoption based on previous efforts of introduction, education and technical assistance. Residents in MWXCV understood the benefits of AD through the leaders' educational efforts and were then eager to adopt the technology when it became financially viable especially with financial compensation from the government. Once AD is incorporated into rural people's livelihood system, the technology can generate a number of benefits, including (1) offsetting energy needs; (2) reducing the reliance on chemical fertilizers while maintaining the nutrient cycle; (3) saving costs on commercial fuels and chemical fertilizers; (4) health improvements; (5) terminating deforestation and improving local environment; and (6) increasing the sustainability of local development more generally.

In order to promote the diffusion of small-scale rural technologies to rural Hainan, several recommendations are provided as policy implications for the Provincial Government of Hainan. Firstly, the government should adopt a ''farmer to farmer'' extension strategy and make special efforts to teach and train the village leaders as extensionists of small-scale rural technologies like AD. Once they understand and accept the technologies, they can teach local residents so as to create a community based multiplier effect. Secondly, in order to have local residents identify the potential benefits of AD, frequent communication and monitoring should be encouraged among the villages. Farmers can learn from each other and the technology can be transferred or duplicated elsewhere more easily. Thirdly, local research institutions should be responsible for providing technical support. Frequent technological seminars and on-site instruction should be provided. Fourthly, a number of offices should be established at village-cluster level across the rural areas as facilitators of technology diffusion. They should be responsible for the implementation of governmental strategies, principles and regulations, as well as providing the necessary technical support and budget assistance. Finally, it is necessary for the governments at all levels to provide financial incentives for the diffusion of AD technology. The current financial incentive and compensation policies are effective and should be maintained. In order to achieve a wider extension of the technologies, more financial incentive programs are suggested.

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