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Health, Ecological, Energy and Economic Impacts of Integrated Agricultural Bioenergy Systems in China and Institutional Strategies for Their Successful Diffusion

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TABLE OF CONTENTS

LIST OF TABLES iii
LIST OF FIGURES v
EXECUTIVE SUMMARY vii
Section 1
Literature Review 1
1.1 Background 1
1.2 Brief Description of Anaerobic Digestion 3
1.3 Current Status of AD Technology Development and Applications in Selected Countries 4
1.3.1 China 4
1.3.2 India 7
1.3.3 Nepal 7
1.3.4 United States 8
1.4 Objectives 9
Section 2
Technical Description of Integrated Agricultural Bioenergy Systems 11
2.1 Introduction 11
2.2 Northern Model 12
2.3 Southern Model 14
2.4 Design of the System 14
Section 3
Methodology for IAB System Evaluation 17
3.1 Background 17
3.2 Economic and Financial Analysis 18
3.3 Economic Analysis of Energy and Environmental Factors 19
3.4 Economic Analysis of Health and Other Social Effects 21
3.5 Other Quantified and Unquantified Benefits 22
3.6 Sensitivity Analyses 23
Section 4
Social-Economic Profiles of Two Provinces 25
4.1 Social-Economic Overview 25
4.2 Brief Description of the Study Design 26
4.3 Profile of Two Selected Provinces 27
4.4 Rural Energy Service and Assistance Framework in China 28
Section 5
Social-Economic Assessment of the IAB Systems in Liaoning 31
5.1 Households Profile – Size, Income, Expenditure and Education 31
5.2 Agricultural Productivity 32
5.3 Energy Consumption 35
5.4 IAB System Impacts 38
5.5 Environmental Impacts 40

5.6 Policy Preferences 43
Section 6
Social-Economic Assessment of the IAB Systems in Yunnan 45
6.1 Households Profile – Size, Income, Expenditure and Education 45
6.2 Agricultural Productivity 46
6.3 Energy Consumption 49
6.4 IAB System Impacts 50
6.5 Environmental Impacts 52
6.6 Policy Preferences 55
Section 7
Multi-Dimensional Analysis of IAB and CAE Systems 57
7.1 Introduction 57
7.2 Financial Analysis 59
7.3 Environmental and Health Analysis 61
7.4 Analysis of Energy Savings and Greenhouse Gas Reduction Potential 62
7.5 Water Impact Analysis 64
7.6 BCR Estimates with Selected Coaial and Environmental Effects Considered 66
7.7 Discussion of Qualitative Benefits 67
7.8 Sensitivity Analysis 69
7.9 Prediction of the Potential Market Size of IAB Systems in Two Provinces and China 69
7.10 Conclusions 70
Section 8
Barriers Analysis and Policy Options for IAB System Development 71
8.1 Barriers to IAB System Development and Adoption 71
8.2 Policy Options for IAB System Development 72
8.3 Future Research Needs 73
Bibliography 75
ANNEX A: Survey Template for IAB system in China 81
ANNEX B: Survey Template for Non-IAB system in China 95
ANNEX C: Costs and Benefits Used in the Multi-Dimensional Analysis 103

LIST OF TABLES

Table 2.1 Parameters for IAB System Design 15
Table 4.1 Households Sampling in Two Provinces 26
Table 4.2 Socioeconomic Characteristics of Two Provinces in Survey, 2003 27
Table 5.1 Profile of Sampled Households in Liaoning Province 31
Table 5.2 Household Incomes and Expenditures for the Liaoning Survey 32
Table 5.3 Revenue from Agricultural Activities by Household Type for the Liaoning Survey 33
Table 5.4 Expenditures on Agricultural Activities by Household Type for the Liaoning Survey 33
Table 5.5 Household Energy Use by Type of Farm Energy System 36
Table 5.6 Household Energy Consumption and Expenditure by Type of Farm Energy System 36
Table 5.7 Regression Results for the Role of Income and Energy System Type on Household Commercial Energy Demand for Liaoning 38
Table 5.8 Technical Data for Liaoning's "4-in-1" System 39
Table 5.9 IAB Investment Details for Liaoning's "4-in-1" System 39
Table 5.10 Household Financial Sources for IAB System Purchase (Liaoning Survey) 39
Table 5.11 Annual Water Usage by Types of Farm System (Liaoning Survey) 42
Table 6.1 Profile of Sampled Households in Yunnan Province 45
Table 6.2 Annual Household Incomes and Expenditures for the Yunnan Survey 46
Table 6.3 Incomes from Agricultural Activities by Household Type for the Yunnan Survey 47
Table 6.4 Expenditures incurred in Agricultural Activities by Household Type for the Yunnan Survey 47
Table 6.5 Household Energy Use by Type of Farm Energy System for the Yunnan Survey (Percent of households using energy sources) 49
Table 6.6 Household Energy Consumption and Expenditures by Household Type for the Yunnan Survey 50
Table 6.7 Regression Results for the Role of Income and Energy System Type on Household Commercial Energy Demand for Yunnan 50
Table 6.8 IAB Technical Data for Yunnan's "3-in-1" System 51
Table 6.9 IAB Investment Details for Yunnan's "3-in-1" System 51
Table 6.10 Household Financial Sources for IAB Systems (Yunnan Survey) 52
Table 6.11 Annual Water Usage by Types of Farm System (Yunnan Survey) 54
Table 7.1 Key Assumptions 58
Table 7.2 Costs and Benefits in the Multi-Dimensional Analysis (Unit: Yuan) 59
Table 7.3 Financial Analysis of IAB Systems by Province 60
Table 7.4 Financial Analysis of CAE Systems by Province 61
Table 7.5 Heat Value, Combustion Efficiency, CO_2 Emission Factors and Energy Mix for Households Relying on CAE Systems 63
Table 7.6 Annual CO_2 Emission Reductions Associated with the Adoption of an IAB System per Rural Household 63
Table 7.7 Comparison of Benefit-Cost Ratios with Different Savings by Province 65
Table 7.8 Market Potential of IAB Systems in Liaoning, Yunnan and China for the Years 2010 and 2020 69

LIST OF FIGURES

Figure 1.1 Simplified Anaerobic Digestion Process 3
Figure 2.1 Depiction of an IAB System in Rural China 12
Figure 2.2 General Layout of a "4-in-1" Model in Rural China..13
Figure 2.3 "4-in-1" Model Description (Liaoning Province) 13
Figure 4.1 Geographical Locations of Liaoning and Yunnan...26
Figure 4.2 Rural Energy Service and Assistance Framework 29
Figure 5.1 Annual Unit Yield of Vegetables and Fruits by Household Type (Liaoning Survey)..34
Figure 5.2 Annual Revenue from Vegetables and Fruits by Household Type (Liaoning Survey)..34
Figure 5.3 Impact of IAB System Use on Fertilizer Utilization in Liaoning 40
Figure 5.4 Impacts of IAB System Use on Pest/ Insect Problems in Liaoning 41
Figure 5.5 Impacts of IAB System Use on Soil and Water in Liaoning......................................41
Figure 5.6 Impacts of IAB System Use on Environment and Health in Liaoning 42
Figure 5.7 Policy Preferences in Liaoning Province 43
Figure 5.8 The Need for Professional Sludge Service in Liaoning 44
Figure 6.1 Annual Unit Yield and Revenue from Vegetables by Types of Household Energy System (Yunnan Survey)..48
Figure 6.2 Impacts of IAB System Use on Fertilizer Utilization in Yunnan...............................52
Figure 6.3 Impacts of IAB System Use on Pest/ Insect Problems in Yunnan 53
Figure 6.4 Impacts of Environment Quality and Health with IAB System in Yunnan Province 53
Figure 6.5 Impacts on Environment Quality and Health with IAB System in Yunnan Province 54
Figure 6.6 Policy Preferences in Yunnan Province 55
Figure 6.7 The Need for Professional Sludge Service in Yunnan 56
Figure 7.1 Sensitivity Analysis for IAB System Purchase in Liaoning.......................................68
Figure 7.2 Sensitivity Analysis for IAB System Purchase in Yunnan 68

EXECUTIVE SUMMARY

Research done by the China Ministry of Agriculture and the U.S. Department of Energy has estimated that there are about 604 million tons of agricultural residues (straw and stalk) produced in China annually, which could be transformed into energy as cooking fuel or as feedstock for digesters that produce biogas (Li & Zhou et al, 1998) . Presently, these residues are used for cooking, heating and lighting in rural households, or as forage for animals, raw materials for industry (mainly the paper industry), or organic fertilizer (Li & Zhou et al, 1998). Greater efficiency is possible, than is presently achieved, in the utilization of agricultural residues to enable economic and environmental sustainability. Efficiency improvements would enable China's agriculture to be competitive in a global economy.[1]

China is a world leader in the development and application of anaerobic technologies for the production of fuel gas and treatment of wastewater (China Ministry of Agriculture, 2000 and 2001; Li, Zhuang, DeLaquil & Larson, 2001). With individual household-scale biogas digester technology developed in the early 1950s, a program of technical support and technology dissemination was implemented throughout China. This program has resulted in biogas digesters being widely used to provide fuel gas for rural household heating, lighting and cooking. By 2003, there were more than 10 million Chinese households with biodigesters and more than 2,000 medium- and large-scale biodigesters which could generate nearly 4 billion cubic meters of biogas annually (Zhang, 2004).

Faced with the challenge of population growth and limited expanses of cultivatable land, China has had marked success in feeding 22% of the world's population (1.3 billion) on 7% of the world's cultivatable land (Ye et al, 1997; Wang 2002). Recent increases in China's agricultural yields have mostly resulted from the greater use of chemical fertilizers and pesticides (Yan et al, 1999). But, their applications can cause ecological stress (notably, soil degradation and species extinction – see Wang, 1999; Ye et al, 2002). Agricultural yields could also be improved if farmers use organic nutrients (including

[1] China's entrance into the World Trade Organization in 2001 has resulted in increased pressure to open its economy to agricultural products from international sources.

agricultural residues) more efficiently. In this way, farmers could improve agricultural production while also protecting the natural resource base.

The purpose of this study is to assess the Health-Ecological-Energy-Economic (HE^3) impacts of Integrated Agricultural Bioenergy (IAB) systems for rural areas of China. The IAB system is an innovative approach that seeks to enhance the efficiency of agricultural residue utilization. We provide an analysis of the full life-cycle costs and benefits of IAB systems, including their contributions to energy savings, CO_2 emissions reduction, agricultural waste reduction, higher rural incomes, better rural health, and ecosystem sustainability. Our analysis relies on qualitative and quantitative modeling in order to produce a comprehensive assessment of IAB system impacts. Importantly, the research is based on actual IAB systems in use in Liaoning and Yunnan (see map on page 26).

Enhanced Agricultural Productivity

When IAB systems are used by rural households, conventional agricultural "waste" is transformed into a useful resource that can yield energy (biogas) for various purposes (e.g., cooking, heating, lighting, and power generation ─ together with a diesel engine). Further, it can produce "green" fertilizer (as a sludge that performs better than farmyard manure), which can increase agricultural productivity in the cultivation of fresh vegetables, fruits and flowers and is also available during the winter when cash values for certain crops are much higher. Use of the sludge from IAB systems enhances productivity, yielding much higher outputs (compared to conventional open and direct applications of animal and human wastes) because the sludge not only contains nitrogen but also phosphorus and potassium that are also valuable plant nutrients. In addition, the greenhouse (found in northern China's so called "4-in-1" type of IAB systems ─ see Chapter 2) mostly utilizes solar isolation to maintain higher ambient temperatures (10°C warmer) in winter. This has collateral benefits for pig-raising when the pen is located next to the greenhouse (the typical "4-in-1" design calls for this), since warmer temperatures during the winter enhance pig growth. The increased CO_2 concentration inside the greenhouse, due to releases from pigs grown in conjunction with the greenhouse, combines with higher ambient temperatures to stimulate crop growth and increased productivity through active photosynthesis.

Increased Household Income

Biogas is an ideal fuel to meet rural residential energy demand (especially, cooking, lighting and heating). It is clean-burning, thereby causing little or no indoor pollution during combustion, and is a locally available renewable source. Biogas can be readily produced cheaply with indigenous technology. China's celebrated "4-in-1" system is estimated to be used by 2.1 million rural households and its "3-in-1" variants for warmer climates is used by 8.1 million rural households (see State Development Planning Commission, 2000). IAB systems reduce not only conventional energy consumption, but also diminish the need for fertilizers and pesticides (through effective use of its sludge), thereby reducing household expenses. As well, higher agricultural productivity resulting from the use of organic nutrients as fertilizer adds to farm income (see Sections 5-7 below).

Health Benefits

In rural areas in China, an open fire inside the dwelling is commonly used for cooking and heating. Even though biomass does not contain many non-combustible contaminants, the emission of health-damaging pollutants in the form of incomplete combustion products can be quite high. IAB systems allow users to switch their stoves from less energy-efficient, smoky and polluting wood, coal or agricultural residues to more efficient and clean-burning biogas. Air quality in the kitchen is thereby improved and the incidence of ophthalmic and respiratory diseases can be reduced (MOA, 1995).

Raw manure spread over fields is considered a key cause of water pollution and is also linked to outbreaks of phisteria, an algae that is lethal for fish and harmful to humans (Chen, 1997). Further, this practice is associated with various diseases that afflict humans, not the least among there being gastrointestinal ailments associated with high bacterial loads in food and water (Wang, 2001). The IAB system offers a means of reducing this problem. The system effectively destroys the eggs and bacteria in animal and human waste through aerobatic fermentation, resulting in a drastic reduction in the pathological load of farm fertilizer in the form of sludge (Chen, 1997; Wang 2001). As well, it results in the reduction of mosquitoes and housefly populations (Chen, 1997; Wang 2001). All of these effects improve the ambient environment for rural households.

Energy and Environmental Benefits

Measured gains in energy efficiency and reductions in fertilizer and pesticide use are reported in the study. Reduced dependence on fuelwood and coal that results from biogas substitution lowers CO_2 emissions (and SO_2 emission when replacing coal consumption). Further, it checks land degradation resulting from the felling of trees for fuelwood and charcoal production. Use of biogas also frees up the use of non-woody biomass, such as stalks, husks, and other agricultural residues, that would otherwise be consumed for cooking. Instead, the non-woody biomass can be used as compost for green fertilizer, which can improve agricultural productivity through the return of nitrogen to soil. The IAB system also provides a sludge that can be applied as farmland fertilizer, again supplying ecosystem benefits while increasing agricultural output per unit of land.

Impact on Water Usage

Liquid sludge produced by IAB systems can be used to irrigate farmland, which would increase plot yields and, at the same time, reduce the level of required irrigation (thereby reducing water consumption). The sludge can also increase the amount of organic complement returned to a farm's soil. This would provide a collateral benefit of increasing the water retention capacity of a farm's soil.

The winter greenhouse, in the case of 4-in-1 systems, can reduce evaporation, thereby lessening water demand as well. In rural areas of China where water is scarce, this supplies an obvious benefit. Thus, IAB systems can offer a practical means for water conservation in agricultural production.

An Effective Institutional Framework for Technology Diffusion

While the IAB system yields important economic, social, health and environmental benefits, its initial investment costs are high for most rural households in China. To address this challenge, China needs to build an effective institutional and policy framework, at both the central and local government levels, to promote IAB technology use. Measures can be integrated into the government's overall rural development programs for this purpose.

Presently, central and local government policies do not include specific regulatory measures to support IAB systems development. This research investigates several institutional approaches that might help rural residents to afford such systems. In order to deepen the market and reach rural households with lower incomes, some forms of financing need to be created. In this context, the 'cash only' sale policy in China poses a major barrier. On the basis of our case study, effective ways of disseminating this technology are identified that include a menu of policy options.

Major Findings and Recommendations

1. Agricultural productivity is found to have been enhanced through IAB systems in the two provinces. In Liaoning, the vegetable yield with IAB systems increased twofold over typical systems in use in the province. The "3-in-1" system employed in Yunnan province does not have a greenhouse. As a result, productivity gains are comparatively less dramatic but still substantial. Households with IAB systems in Yunnan produce 1.5 times the amounts of crops as farms relying on conventional energy systems.

2. Based upon a detailed study of 100 household IAB systems, we estimate that farm revenues increase on average by more than 256% in Liaoning and approximately 135% in Yunnan, due to improved agricultural productivity and expanded opportunities for cash-crop farming (especially in the winter season). Results of benefit-cost analyses prepared for this report indicate that IAB systems in both provinces are economically and financially viable. The benefit-cost ratios (BCR) and payback periods for IAB systems are impressive: the simple BCR is 2.63 and the payback period is 2 years for IAB systems in Liaoning; when social and environmental benefits are added (using conservative estimation methods), the

BCR in Liaoning increases to 2.71; in Yunnan, the simple BCR is 1.76, with a payback period of 3 years, and climbs to 2.01 when social and environmental benefits are included. When higher heath costs and soil degradation are considered, the conventional agricultural energy (CAE) system in Yunnan is not viable economically (BCR=0.96), and the CAE in Liaoning is only nominally economic (BCR=1.21).

3. Quantitative and qualitative estimates of the energy and environmental benefits brought about by IAB systems are contained in the report. On average, the annual per household savings in the consumption of coal, LPG and fuelwood are 27.5 kg, 3.6kg and 1,753 kg, respectively, for IAB users in Liaoning. For Yunnan users, savings of 501.6 kg, 0.6 kg and 495.6 kg of fuelwood, LPG and coal are realized. The CEEP research team estimates that commercial energy use is decreased by 36% in Liaoning and 58% in Yunnan among IAB users. This translates to annual economic savings that increase family net income in Liaoning by 1.5% and 11.6% in Yunnan. The reduction in total annual CO_2 emissions per farm household is 45% in Liaoning and nearly 30% in Yunnan.

4. Levels of water savings are quantified in the analysis and proxy values are identified for estimating the economic benefits of such savings. The CEEP research team concludes that IAB-served farms require 16% less water per hectare in Liaoning and 12% less irrigation per hectare in Yunnan, than their counterparts, an equivalent of a 0.14% increase in farm income for Liaoning IAB users and a 0.19% increase in farm income for Yunnan IAB users.

5. The rate of destruction of fecal coli-form bacilla reaches 98 percent and the rate of destruction of the eggs of hookworm reaches 99 percent with IAB systems. As a result, the prevalence of intestinal disease among farmers using the systems greatly decreases. Specific health benefits are quantified in this study. While these benefits are difficult to determine, the CEEP team estimates that IAB users will save an average of 45-60 Yuan (US$5-7) per person per year in avoided health

care fees. Because rural households tend to use health services less often than their urban counterparts and because health care is provided as a social service to all Chinese, this value understates the actual benefit to a farm family.

6. Sensitivity analyses indicate that the economics of IAB systems as whole are not affected by variations in local agricultural taxes. Revenue and production cost variations of -20% to +30% have minor effects on the BCR. In other words, IAB systems do not represent high investment risks for rural households. However, affordability remains an important issue.

7. Although our research shows that IAB systems are economically viable, environmentally beneficial, improve health and pose a relatively low investment risk, many barriers prevent its dissemination and commercialization. These barriers range from lack of financing to a shortage of skilled IAB system technicians to service these systems. Additionally, governmental market programs may be needed to assist farmers in selling the added products resulting from more efficient IAB systems. To take full advantage of the opportunities of IAB systems identified by this report, policies and institutional strategies designed for better dissemination are needed. These include:

    - Extensive Technical Training Programs
    - Creation of Local Biogas Technology Service Centers
    - Establishment of a Commercial Loan Program
    - Launching an Education Campaigns
    - Targeted Assistance for Agricultural Products Marketing.

Section 1

Literature Review

1.1 Background

Developing countries account for 80% of the world's population but consume only 30% of global commercial energy. With increasing population and improved living standards in these countries, the consumption of and demand for energy by developing countries is climbing. There is growing awareness about the need to address energy access and use in new ways. The contributions that renewable energy can make to sustainable rural development are several: it can provide rural energy independence, allow for better health, and improve livelihoods (see Zhou et al., 2002). Renewable energy is also the principal means of mitigating climate change (see IPCC, 2001). One of the most viable sources of rural energy supply is biomass-based renewable energy, which could also contribute to strengthening the rural economy and improving the environment (Ye et al., 2002; Shi, 2001; Li & Min, 1999; Jiang & Shu, 1996; Cheng et al., 1992; Wu et al., 1989; Ma, 1988).

Rural areas in developing countries have a variety of available biomass resources including fuelwood, agricultural residues, animal dung and human wastes (Goldemberg, 1995). Traditionally, biomass is either used directly as fertilizer or burned as a cooking fuel. The direct burning of biomass as fuel is often inefficient because of the low conversion ratio (Li, et al., 2001). It also can be highly polluting due to the production of indoor air pollutants like fly ash and the emission of large amounts of CO_2 into the atmosphere (Florig, 2000; Byrne et al, 1998). Moreover, despite the availability of a variety of biomass resources, it may not be sufficient to meet rural household needs unless different technologies and management approaches are employed. In fact, rural residents in developing countries often resort to the collection of every conceivable kind of burnable material, which can have serious consequences for human health and for the environment (Deng, 1995).

This study focuses upon the case of China, where 22% of the total world's population is fed by 7% of the world's arable lands (Ye et al., 1997; Wang, 2002). Agricultural yields here have substantially increased recently, due mostly to an increase in the use of chemical fertilizers and pesticides. This has, however, also resulted in ecological stresses such as soil degradation and species extinction, which could potentially cause lower yields in the coming years. Such a situation sets in motion a vicious cycle of increased fertilizer and pesticide use, soil degradation and lower yields until the soil cannot support crop growth any longer. This is a negative effect of conventional ideas about agricultural development (Wang, 1999; Zhang, et al., 1986). Chinese farmers, like those of other developing countries, also depend largely upon biomass resources to meet their household fuel needs, creating additional adverse ecological and health consequences.

This situation invites innovative ways to enhance agricultural productivity, address rural energy needs, improve health, and offer ecological protection in rural China. One solution could lie with an integrated system of farming, animal husbandry and biogas generation. In such a system, the generation of biogas (a mixture of methane and carbon dioxide) from the fermentation of agricultural and other wastes could provide a reliable source of energy for rural households. At the same time the sludge and slurry produced as by-products of this fermentation could be applied as organic manure to cultivated fields. By creating access to clean energy and increasing rural agricultural productivity organically, this process could potentially reap multiple economic, ecological and social benefits.

This study explores the health-ecological-energy-economic (HE^3) impacts of a specific integrated agriculture-bioenergy (IAB) system in rural China, and identifies financial mechanisms and policies for dissemination of this system. Below, we briefly describe the process of anaerobic digestion (AD) in order to provide a general understanding of the operation of a biodigester. The current status of biogas technologies in developing and developed countries is also reviewed.

1.2 Brief Description of Anaerobic Digestion

Biogas was first coined as a scientific term in the 17^{th} century after a scientist observed the burning of "marsh gas," as it was called, on the surface of swamps (Van Brakel J., 1980). Anaerobic conditions inside the swamps had caused the decomposition of organic matter resulting in the generation of marsh gas, which escaped to the surface. The term "anaerobic digestion" means the controlled breakdown of organic matter in the absence of oxygen. It is a two-stage biological process, each stage being performed by a distinct group of bacteria. In the first stage, acid forming bacteria convert organic matter anaerobically into simple organic acids, while in step two methane forming bacteria convert these organic acids anaerobically into biogas (see Figure 1.1).

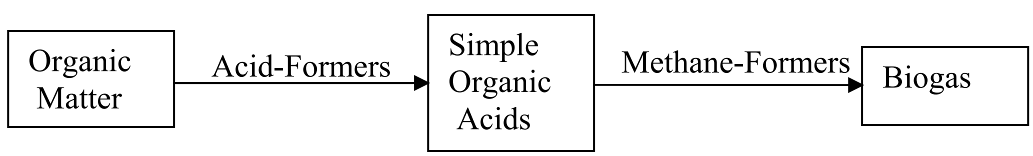

Figure 1.1 Simplified Anaerobic Digestion Process

Biogas is a mixture of nearly 60 percent methane (CH_4) and 40 percent carbon dioxide (CO_2) that is adulterated with a nuisance amount of water vapor (H_2O) and hydrogen sulfide (H_2S). It is called biogas to differentiate it from the high-grade form of methane known as natural gas.

The benefits of AD include:

1.) Odor reduction;
2.) Lower biological oxygen demand by effluent (up to 90 percent), decreasing the risk of water contamination;
3.) Improved nutrient application control, because about 70 percent of the nitrogen in the waste is converted to ammonia, the primary nitrogen constituent of fertilizer;

4.) Reduced pathogens, viruses, protozoa and other disease-causing organisms in wastewater, resulting in improved human and herd health and possibly reduced water requirements; and
5.) Renewable energy supply (biogas) (Wang, 2001).

1.3 Current Status of AD Technology Development and Applications in Selected Countries

A biodigester primarily consists of an airtight and watertight chamber known as the biogas plant. Inside the biogas plant, organic matter, in the form of agricultural residues, other biomass, and human and animal wastes, is subject to various chemical and microbiological reactions occurring under anaerobic conditions, to produce biogas. The biogas plant can be constructed from different materials and there are variations in shape and size. The material, shape, size and other design considerations depend upon local conditions, biogas requirements and financial factors. The construction cost of the biodigester represents the major portion of the initial investment. Commonly preferred designs for rural household application are the floating drum and fixed dome types of digesters.

Energy from biomass normally provides the largest share of energy supply in rural areas of developing countries. According to UNDP and World Bank estimates (based on investigations in 15 developing countries), household energy consumption accounts for 30-95% (compared with 25-30% in developed countries) of total energy use. In the following section, we examine anaerobic digester applications in several countries.

1.3.1 China

China is a large developing country with the world's largest population. Agriculture constitutes the primary occupation of its citizens, while poverty alleviation and the satisfaction of basic human needs remain urgent priorities. The primary source of energy for rural Chinese residents is biomass in the form of crop residues, firewood and other organic wastes. It accounts for about 70% of the energy consumption by rural Chinese households (*China Rural Energy Statistical Yearbook, 1997*). However, the often incomplete combustion of these materials can result in severe indoor air pollution because of dispersed suspended particulates, which cause respiratory illness of household members. On the other hand, the availability of bioenergy sources is limited and energy shortfall can severely restrict the growth of the rural economy and improvement in living standards (Zhou A. et al., 2002; Ye, 2002). Rural energy development is, therefore, directly linked to people's living standards, the improvement of the environment and the sustainable development of the rural economy.

To satisfy rural energy demand, small- and medium-scale anaerobic digester systems have been introduced in China over the past several decades via the country's rural energy construction program. Biogas was first introduced in China in the 1930s and individual household-scale biogas digester technology was developed in the early 1950s. Subsequently, a series of programs for technology development, technical support, and dissemination were implemented in China, which resulted in biodigester technology being adopted by many farms to provide fuel gas for heating, lighting and cooking in rural households (Shi, 2002).

Development of biogas technology in China has been a priority for the Ministry of Agriculture since the 1970s. A nationwide network for research on biogas technology development and its application has been established. However, these commitments have not been maintained. As a result, outdated technology and weak technical and institutional support can be found in many regions (MOA, 2000). Financial, institutional and operational problems are cited as the main reasons behind the decline in the number of operational biogas plants.

Recently, the Chinese government has launched research and development to further improve biomass and bioenergy technologies. Notable achievements include large- and medium-size husbandry farm biogas engineering technology, straw and stalk gasification technology for central gas supply, and refuse landfill power generation (Zhang et. al., 1999). By the year 2003, there were more than 10 million Chinese households with biodigesters and more than 2,000 medium- and large-scale biodigesters which could generate nearly 4 billion cubic meters of biogas annually (Zhang, 2004).

At present integrated biogas use is becoming very popular in rural China and there exist different models for making use of the process of biogas generation for energy to serve multiple needs. For example, “energy-environment-agriculture projects” and “ecological garden projects” attempt to combine biogas generation technology with agricultural production and environmental protection (Wang, 2001). The ecological model for integrated biogas use, i.e., "pig-biogas-fruit model" (or the so called “3-in-1” model) was developed in South China, and the "rural energy ecological model" (the so called “4-in-1” model) was developed in North China. Both models use biogas as the primary energy source (Lu, 1998).

The fixed dome model of biodigester is commonly used in China. It originated in China in the 1930s and consists of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage. In this design, the fermentation chamber and gas storage unit are combined into one facility. This design eliminates the need for the costlier mild steel gas storage tank, which is susceptible to corrosion. According to Liu (2003), a typical farm with 4 persons, raising 6 pigs a year and having an 8 m^3 biodigester could generate approximately 600 m^3 of biogas annually, and around 450 m^3 could be collected for cooking and heating (after conversion and collection losses; and 365 m^3 ofcollectable biogas is feasible for a 6 m^3 biodigester.

However, most rural Chinese households do not have access to financing options like micro-loans for purchasing biogas systems. On the other hand, low quality coal is relatively cheap and fuelwood from forests is “free.” This removes the incentive for the adoption of biogas use among rural households and instead there is continued dependence on traditional fuels for cooking and heating. Application of untreated animal and human wastes to agricultural lands (in lieu of their use in a biodigester to produce organic fertilizer) poses serious health risks. Unless financing (and other) barriers are addressed, it is likely that China’s farmers will not be able to take best advantage of AD technologies.

1.3.2 India

The biogas program in India is a very old one with the primary aim of serving household and community needs in rural areas. Family size units mostly use cattle dung and are aimed at providing clean fuel for cooking purposes. In addition to cooking, these family size plants are also expected to: provide organic manure for agricultural application; reduce the drudgery of fuel wood collection for women; and protect forests as a result of reduced use of fuelwood. As of March 2003, there existed in operation about 3.5 million family type biogas plants and 3,902 community, institutional and night soil based biogas plants. The estimated potential for family scale biogas plants is 12 million (MNES: http://mnes.nic.in/rue2.htm).

The commonly used biogas digester designs in India are the floating drum and the fixed dome types. These biogas designs can handle the high solids content of bovine dung, other animal wastes and agricultural wastes, typically found in India (Reddy et al, 1995). According to Ravindranath et al (2000), it is possible to obtain 35 liters of biogas from 1 kilogram of fresh dung. A typical rural household in India requires 2.5 m^3 of biogas in order to take care of its cooking requirements, which translates to a plant size of 2 m^3 requiring dung from 5-7 cattle (Ravindranath et al, 2000). Another study by Purohit et al (2002) determined that a biogas plant of 1 m^3 capacity, if properly maintained, could possibly meet the cooking energy requirements of a rural family of three to four adults for most of the year. For the purpose of cooking, the biogas user must invest in a biogas plant and biogas burner, a gate valve and a PVC pipe of the required length to transport the gas from the plant to the burner in the kitchen (Kalia, 2000).

1.3.3 Nepal

Nepal has a population of 25 million, of which 90% live in rural areas, and only 10% of its households are connected to the grid. Traditional fuels account for 88% of total energy consumption (72% wood and 16% dung) (Mendis, 2000).

Biogas technology is one of the most reliable rural energy sources used for cooking and lighting in Nepal. Biogas technology has proved to be very successful in the country since it not only produces gas for household purposes but also provides good fertilizer in the form of digested slurry. Biogas was first introduced on an experimental basis in 1955 and a governmental program was launched in 1974 to diffuse the technology to rural families (Mendis, 2000). The national Biogas Support Program (BSP, which established approximately 65,000 biogas plants in Nepal from 1992 to May 2000, serving over 30,000 people) has been considered one of the most successful rural energy programs in Nepal (Nepalnet, 2004; Mendis, 2000). The program's success is the result of standardization of design, an extensive system of quality control and the establishment of financial incentives to potential users for the installation of biogas plants.

Nearly 40 companies have been registered for the installation of biogas plants and more than 49,500 biogas plants are in operation in Nepal. These are largely of the fixed dome design and have been installed in 61 districts of the country. This figure amounts to 3.8% of the country's total potential of 1.3 million (Nepalnet, 2004).

1.3.4 United States

During the energy crises of the mid- and late-1970s, the search for alternative energy resources led to investigation of small- and medium-scale anaerobic digesters developed in India and China to determine whether these technologies were transferable to farms in the United States. Although these technologies are capable of providing fuel for cooking and lighting in developing economies, most are much too small to satisfy the energy needs of the typical American farmer. In the U.S., biogas generated from AD systems serves a number of operations including electricity generation and heat provision, rather than cooking and lighting.

According to Lusk (1999), U.S. livestock operations currently employ four types of AD technology: slurry, plug-flow, complete mix and covered lagoon, which are mainly installed or planned for dairy, swine and caged-layer poultry farms. The first plug-flow digester in the U.S. was designed in 1978 at Cornell University with a capacity to digest the manure from 60 cows (http://www.energy.state.or.us/biomass/digester/digestech.htm). In the U.S., livestock producers have less experience working with anaerobic digesters, with a total of approximately 160 digesters either planned or installed in 1998. The percentage of installed digesters that are not operating is estimated to be nearly 46 percent (Lusk, 1998). The most common reasons that systems are not operating include poor design and installation and poor equipment specification. According to the EPA's AgSTAR Program (2002), there are about 40 digesters already in operation and 30 additional systems planned in 2003. In 35 of the 40 operational systems, the captured biogas is used to generate electrical power and heat. These produce the equivalent of approximately 4 MW per year. The remaining systems flare the captured gas for odor control and reduce methane emissions by about 7,400 tons on a carbon equivalent basis. In total, the operating digesters prevented nearly 124,000 metric tons of methane, on a carbon-equivalent basis, from entering the atmosphere in 2002 (EPA, 2003).

1.4 Objectives

The research project aims to assess the health-ecological-energy-economic (HE^3) impacts of integrated agricultural bioenergy (IAB) systems for rural areas of China. The full life-cycle costs and benefits of energy-saving agricultural production (including CO_2 emissions reduction, agricultural waste reduction, improved rural economies, better rural health, and better ecosystems) are analyzed and quantified.

The objectives are: (1) to compare agricultural productivity between the IAB system and China's conventional agricultural energy (CAE) systems; (2) to assess income differences between households adopting IAB and CAE systems; (3) to evaluate the health and environmental impacts of IAB and CAE systems; (4) to analyze energy and water usage by the two systems; (5) to identify an effective institutional framework for promoting the commercialization and dissemination of IAB systems in rural China.

SECTION 2

Technical Description of Integrated Agricultural Bioenergy Systems

2.1 Introduction

China has experienced rapid economic growth for the past two decades, leading to the conversion of a large amount of arable land is annually converted to industrial, infrastructure or housing uses. The pressure on land and increasing demand on other limited resources has resulted in farmers seeking to increase farm productivity. Ecological agriculture involving integrated utilization and production is an option for responding to these circumstances (Ye, 2002, Shi, 2002).

As Chinese agriculture is increasingly challenged by the constraints of land, resources and environment emerging from its modern development, a sustainable agricultural paradigm may attract interest if it can accommodate economic and socio-cultural needs within an already stressed natural resource base (Shi, 2002). The new integrated agricultural bioenergy systems include a biodigester, a pighouse, a latrine, and land (either open or in a greenhouse) to which digested effluent and/or sludge, (as organic fertilizer) is applied. The IAB system is referred to as a “4-in-1” model when it includes a greenhouse and is considered a “3-in-1” model when a greenhouse is absent (Figure 2.1).

The biodigester utilizes agricultural residues and human and animal wastes from the pigpen and latrine and provides a clean, high quality fuel in the form of biogas to be used for household cooking and lighting (and, in the case of a “4-in-1” system, heating of a greenhouse). The digested effluent and sludge from the digester can be applied as high quality organic fertilizer either on agricultural land or in the greenhouse. The use of organic fertilizer greatly improves soil quality, reduces water demand in comparison to conventional chemical fertilizers and increases agricultural productivity.

2.2 Northern Model

The "4-in-1" system in northern rural China is a courtyard design (Figure 2.1) that dates back to the 1980s. This system includes a biodigester, a pig house, a latrine and a greenhouse. All of these components interact and complement each other to form an ecologically balanced, small- to medium-scale agricultural energy system. As shown in Figure 2.2, a greenhouse is built in the yard; to one side of the greenhouse, a biodigester is constructed underground; and a pig house is built above it. In one corner of the pig house, a separate latrine for the household is constructed. Thus, human and animal wastes directly flow into the biodigester to generate biogas and green fertilizer through AD. The greenhouse produces vegetables and fruits by utilizing solar energy, biogas powered lighting and heat, and organic fertilizer from the biodigester, as described in Figure 2.3.[2] The presence of pigs in the pighouse and the burning of biogas for lighting in the greenhouse help to increase the CO_2 concentration here, thus aiding plant productivity.

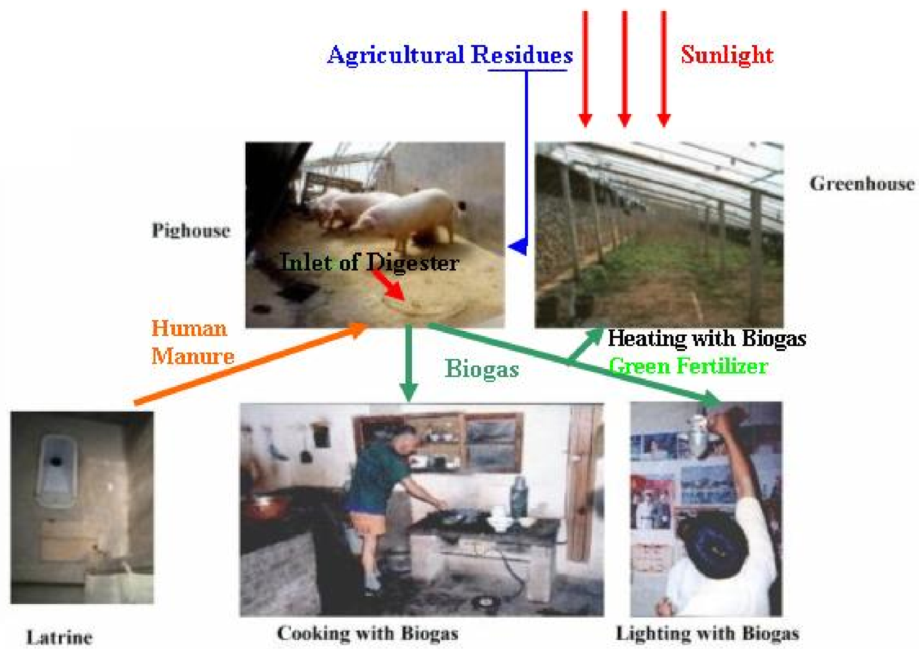

Figure 2.1 Depiction of an IAB System in Rural China

[2] Photos provided by Jingming Li of the Chinese Ministry of Agriculture and South-North Institute for Sustainable Development (China).

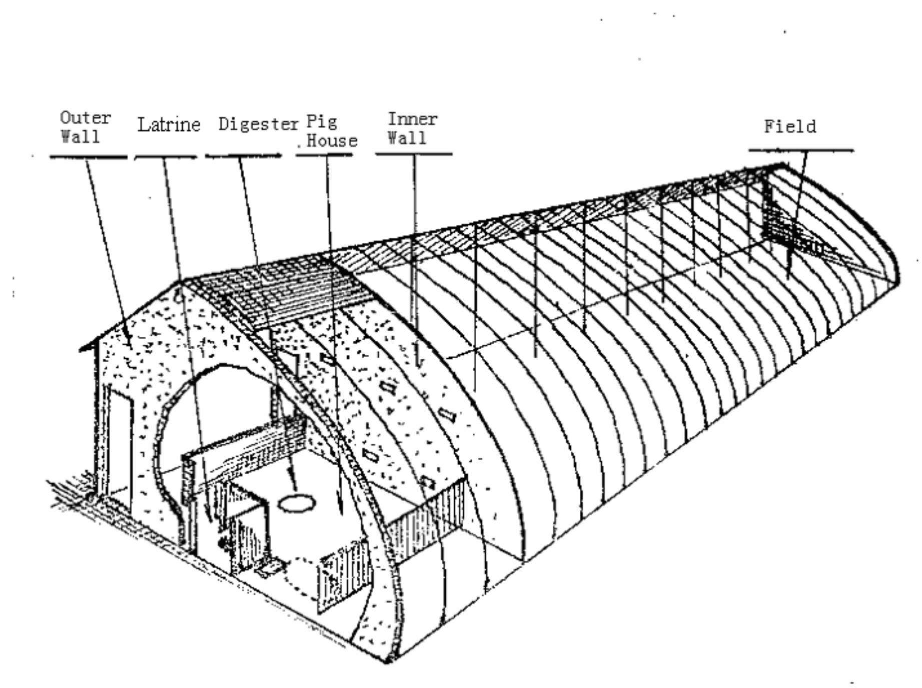

Figure 2.2 General Layout of a "4-in-1" Model in Rural China

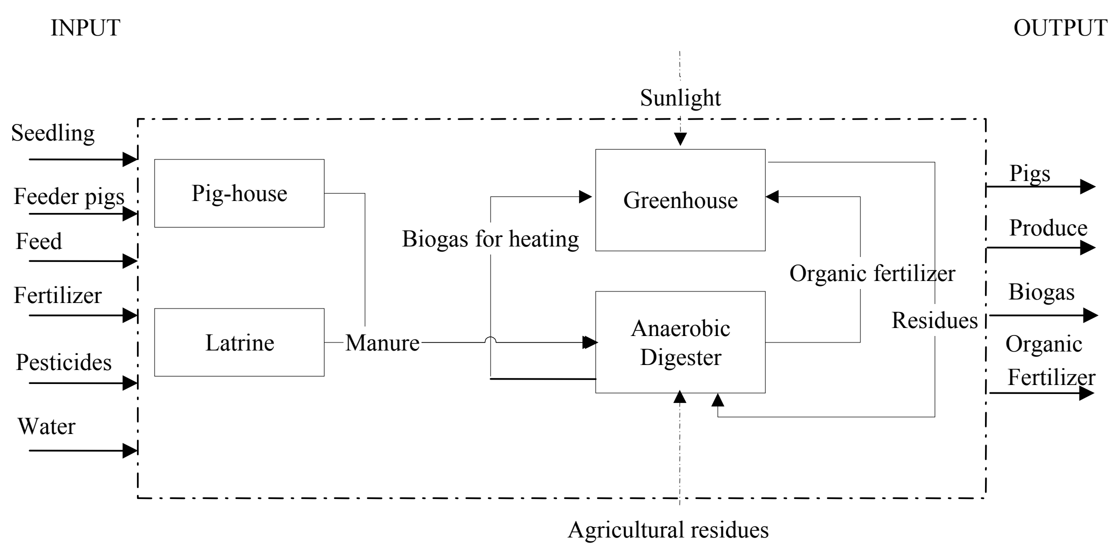

Figure 2.3 "4-in-1" Model Description (Liaoning Province)

Since the 1990s, larger IAB systems have been advocated to take advantage of possible economies of scale. A typical 4-in-1 system has now expanded from a household yard sized system to a field sized one. Large systems have greenhouses, ranging from 300 m^2 to 700 m^2, a biodigester with a volume between 6-12 m^3, and a 20 m^2 pig house.

2.3 Southern Model

In southern rural China, "3-in-1" systems are popular. The three elements of this system are pigs (or other domestic animals), an orchard or vegetable growing plat, and a biodigester. This type of "pig-biodigester-orchard" system is the main type of the "3-in-1" model. The Chinese government advocates the adoption of the "3-in-1" system for every southern rural household and it includes one biodigester, a pigpen that can raise two pigs per capita per year, and a farm that cultivates around 1 Mu[3] of orchard area.

2.4 Design of the System

The biodigester is the core of the "4-in-1" and "3-in-1" systems and is the most important component for IAB system operation. Several principles guide the design and construction of the biodigester. The biodigester must be:

a.) optimized for nutrient input and output balance, thereby reducing the need for synthetic fertilizers;
b.) oriented toward the maximization of benefits (namely, production of green fertilizer, increased environmental safety, improved sanitary health, and increased agricultural productivity); and
c.) adapted to local conditions.

The entire system must be properly sized in order to make full use of agricultural residues and animal and human waste. Ideally, all nutrients, namely, N, P and K — nitrogen, phosphate and potassium — necessary for agricultural production, must come from the organic fertilizer produced by the biodigester. In order to explain system configuration clearly, the parameters in Table 2.1 are needed.

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[3] Mu is a Chinese area unit; 1 Mu=1/15 ha., or 667m^2.

Table 2.1 Parameters for IAB System Design

Variable	Representation
M (months)	Growth period from feeder pig stage to market pig stage
W (kg)	Weight gained by a pig during period M
Np (kg)	Nitrogen produced by a pig during period M
Pp (kg)	Phosphate produced by a pig during period M
Kp (kg)	Potassium produced by a pig during period M
Na (kg)	Nitrogen produced by an adult human during period M
Pa (kg)	Phosphate produced by an adult human during period M
Ka (kg)	Potassium produced by an adult human during period M
T	Turns of vegetable plantation during period M
Ni (kg)	Nitrogen required for 100kg vegetable production of turn i
Pi (kg)	Phosphate required for 100kg vegetable production of turn i
Ki (kg)	Potassium required for 100kg vegetable production of turn i
Ai (kg)	Amount of vegetable production of turn i per 1000 m^2 greenhouse
H	Household size (number of adults)
B_n, B_p, B_k	Different Numbers of pigs raised during the same period based upon balance of N, P, and K
C_w (%)	Rate of collection of human and animals wastes
L_n (%)	Rate of loss of Nitrogen during the conversion
L_p (%)	Rate of loss of Phosphate during the conversion
L_k (%)	Rate of loss of Potassium during the conversion
S ($1000m^2$)	Area of the greenhouse
RT (day)	Retention time
Ro (ton/m^3)	Density of the input
W (kg/day)	Quantity of water added to biodigester per day
E_p (kg/day)	Daily Excreta per pig (at 100kg weight)
E_a (kg/day)	Daily Excreta per adult
V (m^3)	Biodigester volume
LR (%)	Load rate of the biodigester
$AREA_p$	Area of the pig house

For a fixed area of greenhouse and given household size, the system nutrient balance can be described as follows:

Nitrogen:

$$\sum_{i=1}^{T} \frac{S \times A_i}{100} \times N_i = \frac{12}{M} \times \left(B_n \times N_p + H \times N_a\right) \times (1 - L_n)$$

Phosphate:

$$\sum_{i=1}^{T}\frac{S\times A_i}{100}\times P_i=\frac{12}{M}\times\left(B_p\times P_p+H\times P_a\right)\times(1-L_p)$$

Potassium:

$$\sum_{i=1}^{T}\frac{S\times A_i}{100}\times K_i=\frac{12}{M}\times\left(B_k\times K_p+H\times K_a\right)\times(1-L_k)$$

Therefore, in order to keep the nutrients in the system balanced, the number of pigs raised in the system would be optimized at:

$B=\mathrm{Max}\ (B_n, B_p, B_k)$

The size of the biodigester based upon the number of pigs and size of household can be determined by the following equation:

$$V=\frac{W+B\times Ep+H\times Ea}{\rho\times LR\times 1000}\times RT$$

On average, each pig will occupy an area of 0.8~1.0 m^2 (MOA[4] & Liaoning REO,[5] 1995). Therefore:

AREAp = B×(0.8~1.0).

[4] Chinese Ministry of Agriculture.
[5] Rural Energy Office.

SECTION 3

Methodology for IAB System Evaluation

3.1 Background

To conduct the HE^3 impact assessment of IAB applications in rural China, CEEP designed a comprehensive survey questionnaire and a survey sampling design to statistically represent the variety of rural household IAB system users found in Liaoning Province (northern China) and Yunnan Province (southern China). Two hundred rural households in the two provinces were surveyed by CEEP in close co-operation with its Chinese partners, the Center for Renewable Energy Development of China's Energy Research Institute and the Rural Energy Offices of the two provinces.

The household survey data, combined with socio-economic information at the county and regional levels, was then evaluated using statistical analysis procedures in order to identify the social, economic and technical factors that affect the performance of IAB systems. For the purpose of this research, cost-benefit analysis (CBA) was selected to assess the economic performance of IAB systems. Cost-benefit analysis is a method of economics designed to aid in social decision making about a project. CBA tracks a series of cash flows, and inputs (such as resource use and environmental impact) are converted into monetary flows. If natural phenomena and environmental damage are accurately accounted for in monetary terms, the method can furnish an effective assessment of the net economic effects of IAB system use.

A CBA computation model using Microsoft Excel (MS Excel) was developed specifically for this project. Multi-dimensional criteria of health, ecology, economics and energy are incorporated into the model. This model can process economic and financial data in combination with inputs related to system configuration and relevant social and environmental factors. The model is capable of performing the following functions:

overall economic and financial analysis, economic analysis of energy and environmental factors, economic analysis of health and other social effects, and sensitivity analyses.

3.2 Economic and Financial Analysis

CEEP's model can conduct cost-benefit analyses for owners of IAB systems. Gross costs are composed of annual payments for the system, agricultural taxes, and operation and maintenance (O&M) costs. Annual O&M costs include the cost of feeder pigs, feed, seeds, fertilizer, pesticides and the annual plastic film replacement for the greenhouse (in case of the "4-in-1" model). Gross benefits include cash revenue from the sale of agricultural products and animals; savings on the expenditure of fertilizers and pesticides; energy savings; savings on medical expenses; and environmental benefits including CO_2 emission reductions.

Annual payments are calculated using the PMT[6] function in MS Excel©. The model also calculates annual balances, annual interest (if the system is constructed with the aid of a loan from commercial banks) and annual returns. Annual interest equals the interest on the loan, and it is estimated using the IPMT[7] function. Annual principal is the outstanding loan amount, and it is estimated by the PPMT[8] function. The annual balance is the remainder (surplus or debt).

Net cash flow is calculated as the difference between gross benefits and gross costs. Net present value is the sum of the net cash flow value discounted by the selected discount rate. The benefit-cost ratio is calculated as the sum of present gross benefits divided by the sum of present gross costs. The model defines the payback period as the time when cumulative cash flow using the annualized O&M costs becomes zero or positive for the first time. If the benefit-cost ratio is less than 1.0, total costs cannot be paid from total revenues and no payback period is calculated.

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[6] PMT calculates the payment for a loan based on constant payments and a constant interest rate.
[7] IPMT returns the interest payment for a given period for an investment based on periodic, constant payments and a constant interest rate.
[8] PPMT returns the payment on the principal for a given period for an investment based on periodic, constant payments and a constant interest rate.

3.3 Economic Analysis of Energy and Environmental Factors

Energy saved as a result of biogas use can be calculated from the following equation, based upon the energy balance law, assuming that biogas replaces all other energy sources in the same proportion:

$$\begin{bmatrix} m_{col} \\ m_{lpg} \\ m_{fwd} \end{bmatrix} = V \times \begin{bmatrix} \lambda_{col} \\ \lambda_{lpg} \\ \lambda_{fwd} \end{bmatrix} \begin{bmatrix} \frac{\eta_{bio}}{\eta_{col}} & \frac{\eta_{bio}}{\eta_{lpg}} & \frac{\eta_{bio}}{\eta_{fwd}} \end{bmatrix} \begin{bmatrix} \frac{h_{bio}}{h_{col}} \\ \frac{h_{bio}}{h_{lpg}} \\ \frac{h_{bio}}{h_{fwd}} \end{bmatrix}$$

Where:

V: Volume of biogas production each year (m^3);

h: Heat value (MJ/m^3 for biogas, and MJ/kg for coal, LPG and fuelwood);

η: Combustion efficiency (%);

λ: Percentage of the energy mix (by weight) represented by each source.

col: Coal;

lpg: LPG;

fwd: fuelwood.

The price of biogas is determined by the following equation:

$$P_{biogas} = \frac{\sum_{i=1}^{3} P_i \times m_i}{V_{biogas}}$$

Where:

P: Price (Yuan/m^3 for biogas, Yuan/kg for coal, LPG and fuelwood);

V: Volume of biogas production each year (m^3);

m: Energy consumption in households without IAB systems

i: i=1 for coal; i=2 for LPG; and i=3 for fuelwood.

There is no net emission of CO_2 during the use of biogas as an energy resource. The carbon dioxide released during biogas combustion was originally organic plant material and therefore is completing a cycle from atmosphere to plant to animal and human use, and back to the atmosphere.

This model estimates the quantity of CO_2 emissions that can be avoided by IAB systems as a result of bioenergy replacing other energy sources. The amount of CO_2 emission change is determined by

$$\Delta = \sum_{i=1}^{3} \varepsilon_i \times h_i \times m_i - \varepsilon_{biogas} \times h_{biogas} \times V_{biogas}$$ [9]

Where:

Δ: CO_2 emission reduction (ton);

ε: CO_2 emission factor;

h: Heat value (MJ/m^3 for biogas, and MJ/kg for coal, LPG and fuelwood);

m: Energy consumption in households without the IAB system;

V: Volume (m^3)

i: i=1 for coal; i=2 for LPG; and i=3 for fuelwood.

The annual environmental benefit from CO_2 emission reduction is estimated by

$$B_{co_2} = C_{co_2} \times \Delta$$

Where:

B_{co_2} : Annual environmental benefit from CO_2 emission reduction (Yuan);

[9] When bioenergy replaces a source with higher carbon content, there is net reduction in CO_2 emission. If bioenergy replaces a source with lower carbon content, net CO_2 emissions increase.

C_{co_2}: Cost of CO_2 emission mitigation (Yuan/ton);

Δ: CO_2 emission change (in tons).

3.4 Economic Analysis of Health and Other Social Effects

In addition to possible increases in income, reduction in fossil energy use, and CO_2 emission reductions, IAB systems can also have positive impacts on human living conditions, animal health and the environment.

In the case of IAB systems, human and animal waste mixed with wastewater is carried to the biodigester (underneath the pigpen) where it is anaerobically digested. This effluent and sludge is a high quality organic fertilizer, rich in humus, which is economically beneficial for Chinese farmers. It is also free of odor, disease pathogens and weed seeds because the process of anaerobic digestion efficiently kills pathogens and parasite eggs. According to Li and Wang (2000), the rate of extinction of fecal coli-form bacillus reaches 98 percent and the rate of extinction of the eggs of hookworm reaches 99 percent. As a result, the prevalence of intestinal disease among farmers can greatly decrease. Anaerobic digestion also removes 80 percent of the BOD. Proper disposal and treatment of human and animal waste via an IAB system can improve sanitary conditions, thereby contributing to improved water quality.

An IAB system also produces a high quality source of energy in the form of biogas as described previously, which is a clean –burning fuel and generates only water vapor and CO_2. There is therefore potentially a significant reduction in the prevalence of health problems among women and children, especially respiratory and eye problems, associated with fuelwood burning.

The health benefits of IAB systems for rural family members can be expressed by the following equation:

$$B_{mf} = E_{mf-without} - E_{mf-with}$$

Where:

B_{mf}: Health benefit;

$E_{mf\text{-}without}$: Medical expenditures on eye and inhalation diseases in households without IAB systems;

$E_{mf\text{-}with}$: Medical expenditures on eye and inhalation diseases in households with IAB systems.

The health benefits of IAB systems in the case of animals can be expressed by the following equation:

$$B_{ma} = E_{ma-without} - E_{ma-with}$$

Where:

B_{ma}: Health benefit;

$E_{ma\text{-}without}$: Medical expenditures for treatment and control of animal diseases in the absence of an IAB system;

$E_{ma\text{-}with}$: Medical expenditure for treatment and control of animal diseases in households with IAB systems.

3.5 Other Quantified and Unquantified Benefits

There are also other environmental and health benefits associated with IAB systems, such as soil improvement, that are relatively difficult to quantify (although many researchers have attempted to do so ─ see Wang M.J., 2001; MOA, 2000; Ye & Wang, 1999; Chen, 1997). Organic fertilizer from IAB systems replenishes the land with macro- and micro-soil nutrients. Research conducted by China’s Sichuan Provincial Academy of Agriculture (Li & Wang, 2000) found that the content of organic matter, nitrogen, and phosphorous in soil increased by about 0.17%, 0.04% and 0.014%, respectively after 4 years of application of organic fertilizer from a biogas digester. A decrease in the unit weight of soil by about 0.03g/cubic centimeters was observed and there was an increase in soil porosity of about 0.93%. It was also observed that the thickness of the living soil layer increased from 34 cm to 42 cm. These benefits are very important and are expected to increase over the long term. A proxy value for this benefit would be reduced fertilizer requirements.

China is not particularly well endowed with water, yet water has been used as a cheap resource for agricultural and industrial production. Increasing demand, limited surface water availability and reliability, and rising reliance on groundwater extraction have led to falling water tables and several other problems in northern China (Lohmar et al., 2003). The organic fertilizer from IAB systems reduces evaporation losses from the soil surface, thereby conserving water for plants. Mulching with organic fertilizer and crop residues can usually improve soil moisture retention rate by 30-50% (Zhu, 2002). Current water prices for agricultural users in China differ slightly from region to region. In the late 1990s, agricultural surface water was priced at about 0.03 Yuan per cubic meter in Yunnan and 0.05 Yuan per cubic meter in Liaoning, where water shortages are acute. However, these water prices are only 25% of supply cost (Jiang, 1999). For this analysis, unsubsidized water prices were employed to estimate conservation benefits from IAB system use.

3.6 Sensitivity Analyses

In CBA, there always exists some uncertainty about the magnitude of the impacts predicted and the value assigned to different factors. In situations involving risk (i.e., farmers risking their investment), sensitivity analysis is often required in a dynamic CBA computational model.

The most commonly used approach, partial sensitivity analysis, is adopted in this report to determine the changes in the benefit-cost ratio with variations in several factors under consideration. The three key factors under consideration for the purpose of this analysis were revenue, production cost and agricultural taxes. CEEP's computation model analyzes each variable, with values ranging from a decrease of 20% to an increase of 30%.

SECTION 4
Social-Economic Profiles of Two Provinces

4.1 Social-Economic Overview

The findings presented in this report are based upon a field survey and interviews of 200 households in the two provinces of Liaoning and Yunnan (See Figure 4.1). In each province, 100 households were interviewed — 50 who have integrated agricultural bioenergy systems and 50 who rely on conventional energy sources. In both provinces, interviews were conducted by CRED researchers (accompanied by provincial rural energy officers) using formal surveys designed by CEEP and CRED staff. Interviews were conducted in Chinese, tallied in Chinese and translated in English (see Annex A and B for English versions of the survey instruments). To understand the impact of the installation of IAB systems, we researched both groups of households — those with and without IAB systems — on a variety of variables, including agricultural practices, agricultural performance, household income, health, socio-economic indicators, and environmental issues.

All IAB systems used in Liaoning province were of the 4-in-1 configuration, whereas all the systems used in Yunnan province were of the 3-in-1 configuration. An equal number of households relying on traditional energy sources in each province were interviewed with attention to the same variables.

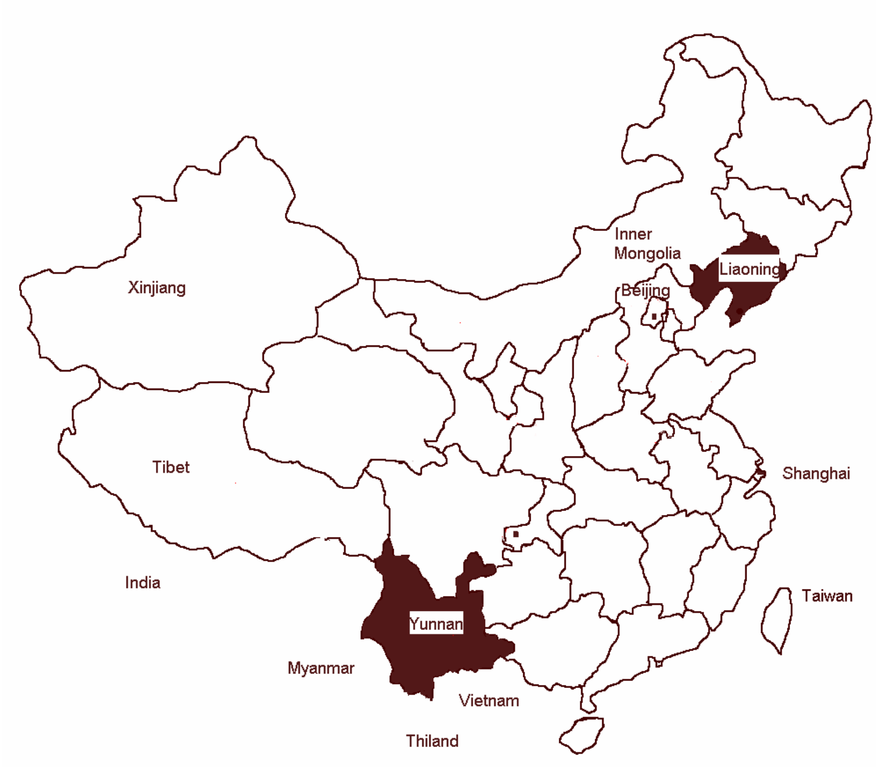


Figure 4.1 Geographical Locations of Liaoning and Yunnan

4.2 Brief Description of the Study Design

The samples of households in the two provinces were drawn so as to be representative of households with and without IAB systems. Details about the survey design are described below.

Sample Size: 200 households in two provinces

Table 4.1 Households Sampling in Two Provinces

	IAB System User	CAE System User
Liaoning	50	50
Yunnan	50	50

Household Selection Criteria:

- Households were selected which are typical of the range of income and family size in the province's farming villages.
- Households were chosen that had at least 2 years experience with either an IAB system or a conventional wood/LPG/coal-based energy system.
- At least 20 female heads of households were surveyed in each province (10 or more who were familiar with IAB systems, and 10 or more who used conventional systems).

4.3 Profile of Two Selected Provinces

The two provinces studied for this report have sizable rural populations. Liaoning Province is located in the northern part of China, and Yunnan is located in the south, sharing a border with Vietnam, Myanmar and Thailand (see map above). The provinces cover an area of 0.54 million square kilometers (0.15 million square kilometers in

Table 4.2 Socioeconomic Characteristics of Two Provinces in Survey, 2003

	National	Liaoning	Yunnan
Area Size (10^3 km^2)	9,600	145.9	394.0
Population (millions)	1,284.53	42.03	43.33
Rural Population (millions)	935.03	23.15	34.90
Rural Labor (millions)	485.27	9.94	19.90
Rural Households (millions)	245.69	6.86	8.45
Rural per Capita Annual Net Income (Yuan)	2,475.63	2,751.34	1,608.84
Main Agricultural Products		Grain, oil-bearing plants, beetroots, fruits, hogs	Grain, oil-bearing plants, tobacco, hogs, fruits

Source: China Statistical Yearbook, 2003

Liaoning Province and 0.39 million square kilometers for Yunnan Province), with a total of 15.31 million households living in rural areas (58.05 million people, of which, 23.15 million live in Liaoning and 34.90 million in Yunnan) living in rural areas.

These two provinces are also characterized by different geographic and climate conditions, Liaoning is comprised mainly of plains, with temperature ranging generally from -15 °C to 30 °C; Yunnan offers very different elevations, from mountains to plateaus, and climate varies in its farming areas from 6 °C in winter to 31 °C in summer.

4.4 Rural Energy Service and Assistance Framework in China

In China, the primary government agencies which are engaged in rural energy technology development are: the State Development and Reform Commission (SDRC), (previously known as State Development Planning Commission (SDPC) and State Economic and Trade Commission (SETC)), the Ministry of Science & Technology (MOST), and the Ministry of Agriculture (MOA).

The State Development and Reform Commission (SDRC) is the comprehensive economic management commission in charge of formulating the National Economic Development Plan, Five Year Plans and National Long Term Plans. The Energy Department in SDRC is responsible for formulating the Renewable Energy Yearly and Five-Year Plan, and the Long Term Plan. It is also responsible for formulating the Macro Investment Policy on Renewable Energy Development and Long Term Development Policy on Renewable Energy Industry. The Science and Technology Department is responsible for arranging and regulating the investment on key scientific and technology research projects. The Foreign Capital Utilization Department is responsible for approving foreign capital utilization and foreign company participation in renewable energy projects.

The Ministry of Science & Technology (MOST) is the comprehensive management arm of the Chinese government for the support and promotion of significant national science and technology research. The Energy Division of MOST's Industry and Technology Department is in charge of regulating and organizing the significant science and technology research concerning renewable energy technology. MOST and SDRC jointly formulate the Five Year Plans for science and technology and are responsible for organizing and implementing the renewable energy science and technology research program.

The Ministry of Agriculture (MOA) is responsible for implementing rural energy programs and demonstration projects to improve agricultural production capacity, promote the rural economy and increase farmer's income. It is also responsible for technical assistance and training services for farmers to enable them to utilize renewable energy technology efficiently in farm operations.

The framework of rural energy service and assistance provided by MOA is illustrated in Figure 4.2. The local rural energy offices (REOs) and service stations play a key role in rural energy development in China. Together the REOs and service stations provide technologies and products, installation services, technical assistance and support, local technician training and maintenance services (Li J., 2000).

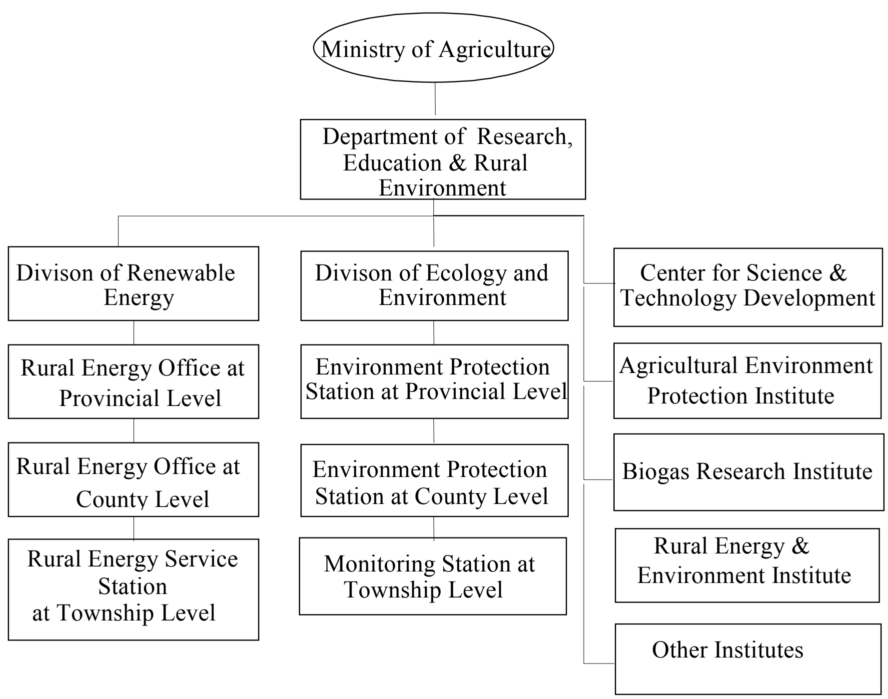


Figure 4.2 Rural Energy Service and Assistance Framework

SECTION 5

Social-Economic Assessment of IAB Systems in Liaoning

5.1 Households Profile – Size, Income, Expenditures and Education

Table 5.1 reports households averages for families with and without IAB systems in Liaoning province. While there is little difference between the two groups regarding household size and labor (see details in Table 5.1), a distinctive difference in net household income can be observed for farms with IAB systems and those that rely on conventional rural energy sources. Households with an IAB system, on average, earn more than twice as much income as those without an IAB system. Reflecting the effect of higher income, farmers using IAB systems have expenditures that are more than twice that of their counterparts. Thus, it appears that the installation of an IAB system significantly improves economic conditions of households in Liaoning.

Table 5.1 Profile of Sampled Households in Liaoning Province

	Farms with IAB Systems	Farms with CAE Systems
Household Size (Persons)	3.2	3.3
Number of Labor (Persons)	2.1	2.2
Average Cultivated Land (1000m^2)	2.87 (0.65[10])	3.85
Annual Household Income (Yuan)	25,208.1	10,880.5
Annual Household Expenditure (Yuan)	10,034.2	5,414.2
Household Net Income (Yuan)	15,173.9	5,476.3
Household Net Income Per Capita (Yuan)	4,741.8	1,659.5

Table 5.2 suggests that among household expenditures, those for agricultural activities consume the largest portion of income of households with and without IAB systems — about 54.8% and 54.5% of the total, respectively. Expenditures for commercial energy are the second largest, accounting for 8.9% (with an IAB system) and 13.6% (with CAE

[10] Average land area for IAB systems per household in Liaoning is 650 square meters.

system) of total expenditures. For households with IAB systems, more than 76% of its annual agricultural expenditures are attributable to the system itself. By contrast, the installation of an IAB system has little effect on expenditures for commercial energy (adding only 84.6 Yuan to the farm's energy bill).

Table 5.2 Household Incomes and Expenditures for the Liaoning Survey

	IAB System User (Yuan/Year)	CAE System User (Yuan/Year)
Total Household Income	**25,208.1**	**10,880.5**
Agricultural activities	23,160.1	8,118.5
Others	2,048.0	2,762.0
Total Household Expenditure	**10,034.2**	**5,414.2**
Agricultural	5,500.3	2,950.7
IAB system-related agricultural expenses	4,185.0	N/A
Commercial energy	894.6	736.4
IAB system-related energy expenses	84.6	N/A
Taxes	113.3	91.1
Insurance	166.7	56.0
Other	3,732.7	1,548.0
Net Income	**15,173.9**	**5,466.3**

The educational level in Liaoning province is comparatively high. All household heads, with or without IAB systems, have received education above the level of primary school. More than half of the household heads surveyed have completed middle school (accounting for the largest share in both categories of households, 59.1% and 51.1%, respectively). Several heads of households with IAB systems received education at the high school level and above (4%).

5.2 Agricultural Productivity

Most farmers in Liaoning earn income from traditional cultivation of cereals, oil-bearing, vegetables and fruits, and domestic animals (mainly hogs). In addition, some households receive income from working in town and village enterprises.

Table 5.3 Revenue from Agricultural Activities by Household Type for the Liaoning Survey

Revenues (Yuan)	IAB System	CAE System
(1)Traditional cultivation	3,133.0	8,217.2
(2) Cultivation with IAB system	17,216.0	N/A
From vegetables	*16,736.0*	*N/A*
(3) Domestic animal and livestock raising	3,115.7	924.2
From hog raising	*3,113.3*	*902.6*
Total revenues from agricultural activities[11] =(1)+(2)+(3)	**23,464.7**	**9,141.4**

Note: This table presents the results of the sample survey. The average revenue of all households classified by household type is slightly different from the results in Table 5.2 because there are a few cases with missing values for those variables.

Table 5.4 Expenditures on Agricultural Activities by Household Type for the Liaoning Survey

Expenditures (Yuan)	IAB System User		CAE System User
		IAB only	
Seedlings	277.8	263.6	721.2
Commercial fertilizer	683.0	140.2	823.1
Pesticides	473.8	55.3	504.0
Animal feed	1,439.8	1,354.2	545.6
Piglets	798.5	760.9	322.8
Plastics for greenhouse	1,757.2	1,744.1	N/A
Others	297.4	249.5	34.0
Total	**5,500.3**	**4,235.9**	**3,003.6**

Note: This table presents the results of the sample survey. The average expenditures of all agricultural activities by household type is slightly different from the results in Table 5.2 because there are a few cases with missing values for those variables.

Figures 5.1 and 5.2 describe the average unit yield and revenue from vegetables and fruit production per 1000m^2 of land for households with and without an IAB system in Liaoning. With respect to vegetable production, households with an IAB system clearly produce larger amounts of vegetables, and accordingly earn more from their production. In fact, households with an IAB system experience yields that are about twice that of farms using conventional agricultural systems (15,550.7 kg/1000m^2 with an IAB system vs. 7,499.6 kg/1000m^2 with a CAE system). Revenues from vegetables (24,337.8

[11] Total revenue from agricultural activities is the summation of revenue from traditional cultivation (1), revenue from cultivation in the IAB system (2) and from livestock raising (3).

Yuan/1000m^2 per household annually) are around 13 times larger than conventional systems (1,897.0 Yuan/1000m^2 per household annually).

On the other hand, a gap such as that seen in vegetable production is not observed in fruit production. The average yield for fruits for farms with IAB systems is almost the same as those using conventional agricultural systems[12] (see details in Figures 5.1, 5.2).

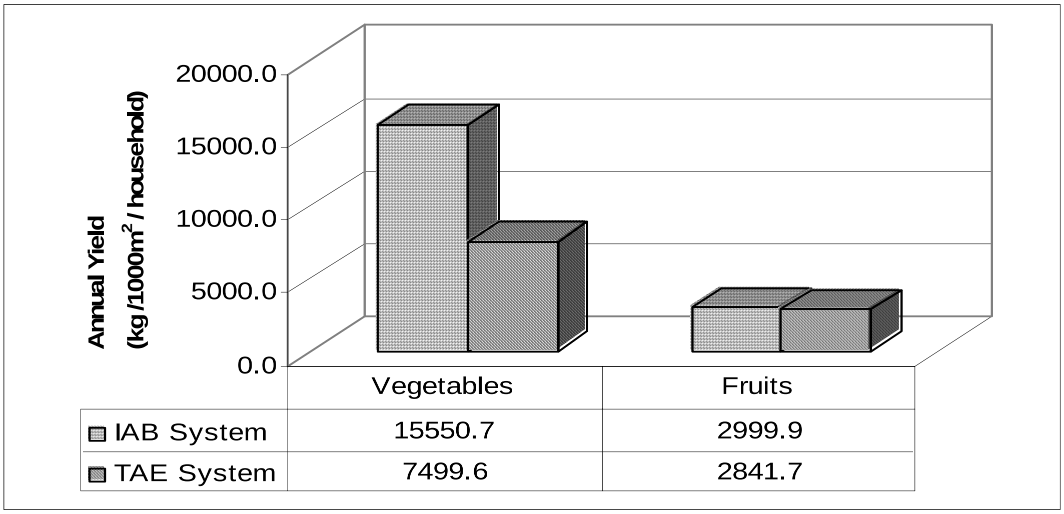


Figure 5.1 Annual Unit Yield of Vegetables and Fruits by Household Type (Liaoning Survey)

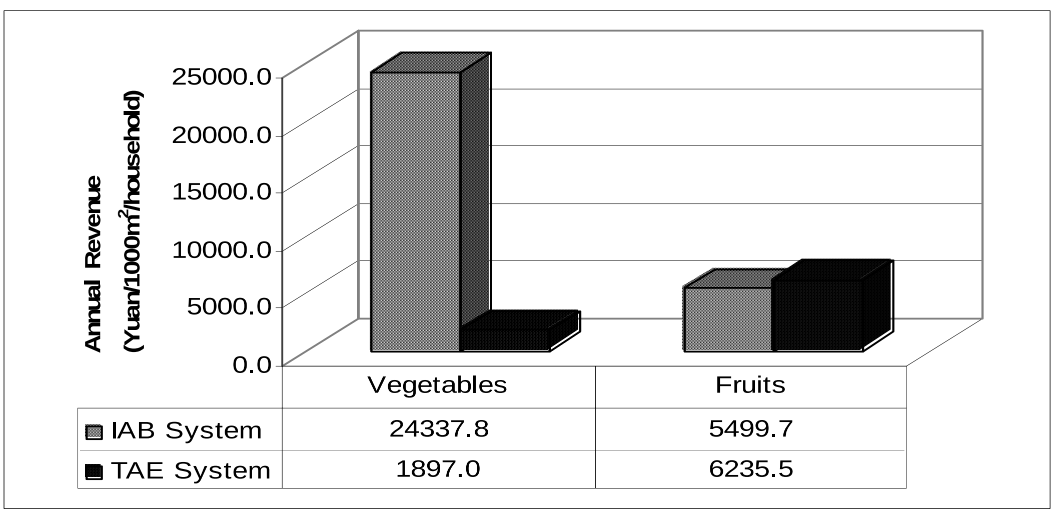


Figure 5.2 Annual Revenue from Vegetables and Fruits by Household Type (Liaoning Survey)

[12] Households surveyed in Liaoning Province did not grow fruits (such as strawberries) and flowers in greenhouses.

In sum, our survey found that households with IAB systems have higher revenues from both agricultural activities and livestock-raising. Average revenues from agricultural activities of households with IAB systems average 20,349.0 Yuan, and this amount is approximately 2.4 times as much as the revenues earned by farms using CAE systems (8,359.4 Yuan). The primary agricultural revenue of farms with IAB systems comes from yields produced by the greenhouse. On average, 85% of total revenue from agricultural activities is from greenhouse production while the rest is from conventional cultivation.

The survey indicates that installation of an IAB system also increases revenue from livestock raising, mainly hog raising. Average revenue from livestock raising for farms with IAB systems is 3,115.7 Yuan, which is more than triple the amount earned by farms using CAE systems (924.2 Yuan). As shown in Table 5.3, almost 100% of revenue from livestock raising comes from hog raising in households with IAB systems.

The survey also found that there is little reduction in chemical fertilizer and pesticide application on farms using IAB systems. From out surveys, it became clear that farmers haven't been informed about the effectiveness of organic fertilizers. With training and plot demonstration projects, it is believed that chemical fertilizer and pesticide use can be reduced.

5.3 Energy Consumption

Household Energy Use Mix

Determining the existing energy use and expenditure patterns among farm households is important for measuring the potential benefit of IAB systems. Table 5.5 shows the survey results regarding energy sources and patterns by types of farm energy system. Five commercial energy sources — electricity, coal, straw, LPG and fuelwood — are popular household choices in Liaoning. Electricity is primarily used for lighting and cooking; coal is used for cooking and heating; straw is used for cooking and heating; LPG is used for cooking; and fuelwood is used for cooking and heating. The difference in the usage of energy sources between households with IAB systems and with CAE systems is that the former applies biogas to lighting, cooking and heating.

Table 5.5 Household Energy Use by Type of Farm Energy System
(Percent of households using each energy source by end use)

		Electricity	Coal	Straw	LPG	Fuelwood	Biogas
IAB System Users	Lighting	100	0	0	0	0	100
	Cooking	96	14	100	100	92	100
	Heating	0	8	94	0	88	100
	Bathing	2	0	0	0	4	0
	Other	0	0	0	0	0	0
CAE System Users	Lighting	100	0	0	0	0	0
	Cooking	58	2	96	94	88	0
	Heating	0	12	98	0	92	0
	Bathing	5	34	0	68	0	0
	Other	0	0	0	0	0	0

Household Energy Expenditures

Households were asked to report their total energy expenditures and amounts physically used. Only commercial energy sources are considered so that biogas is not included here. As shown in Table 5.6, physical amounts used of each energy source by households with IAB systems are slightly larger than those with CAE systems.

Table 5.6 Household Energy Consumption and Expenditure by Type of Farm Energy System

		Electricity	**Coal**	**LPG**	**Fuelwood**
IAB System Users	Physical Amount	624.3 kWh	1.1 ton	2.6 tanks	1667.4 kg
	Monetary value (Yuan)	256.0	441.3	125.5	500.2
CAE System Users	Physical Amount	411.4 kWh	1.0 ton	2.5 tanks	1490.2 kg
	Monetary value (Yuan)	168.7	387.5	116.5	447.1

Note: 1 tank of LPG = 15 kg LPG.

The results reveal that farms with IAB systems spend more on energy than households using the conventional sources. As described below, this is because farms with IAB systems use additional energy to increase agricultural output profitably. This is illustrated by the fact that these farms, while using more energy, devote a similar proportion of their income to this expense category.

In order to analyze the relationship between energy consumption and income, CEEP used a linear regression model to estimate IAB system influence on household commercial energy use. The linear regression models took the following forms:

$$ENG = \alpha_0 + \alpha_1 D + \alpha_2 INCOME + \alpha_3 INCOME\ D$$

Here, ENG = annual household expenditure on commercial energy consumption;

α_i = regression coefficients;

D= dummy variable: 0 for households with CAE systems and 1 for households with IAB systems;

INCOME = annual household gross income.

$$ELEC = \beta_0 + \beta_1 D + \beta_2 INCOME + \beta_3 INCOME\ D$$

Here, ELEC = annual household expenditure on electricity;

β_i = regression coefficients;

D= dummy variable: 0 for households with CAE systems and 1 for households with IAB systems;

INCOME = annual household gross income.

The estimated regression coefficients are identified in Table 5.7 for Liaoning Province. This model shows that households with IAB systems spend less on commercial energy at any given income level as households relying on conventional energy sources (i.e., the α_1 coefficient is negative and statistically significant). Because IAB systems produce biogas, which replaces certain forms of commercial energy, it is also important to consider the impact on electricity demand under similar economic circumstances. The electricity demand model likewise indicates that IAB systems, for a given level of income, reduce electricity needs of farms (i.e., the β_1 coefficient is negative and significant).

Table 5.7 Regression Results for the Role of Income and Energy System Type on Household Commercial Energy Demand for Liaoning

Energy Demand		Electricity Demand	
Estimated Coefficient	**Statistical Significance**	**Estimated Coefficient**	**Statistical Significance**
α_0: 507.11	t=6.77 p<0.000	β_0 :100.65	t=12.07 p< 0.000
α_1:-238.23	t=2.97 p<0.002	β_1: -38.25	t= 5.28 p< 0.000
α_2: 0.0057	t=5.85 p<0.000	β_2: 0.0014	t= 2.55 p< 0.007
α_3: 0.0029	t=3.47 p<0.001	β_3: 0.0017	t= 2.33 p< 0.012

Note: The t-statistic is a measure of statistical significance with t=1.645 representing significance at the 0.05 level.

5.4 IAB System Impacts

Basic Information

IAB systems include a greenhouse which permits continued agricultural production during the winter season. Survey results indicate that the average temperature in the greenhouse in winter is 16 °C, compared to -15°C ~5 °C ambient temperature during Liaonging's winter. Normally, the pigpen area size is 20 m^2, which enables a farmer to raise 3-6 pigs at the same time. The greenhouse requires heating during the winter, and 26 percent of the annual biogas generated from the digester is burned for this purpose, according to our survey results.

The greenhouse also requires lighting for work at night. Survey results suggest that approximately 32 percent of the total farm electricity consumption is for greenhouse lighting among farms with IAB systems.

Technical and Financial Data

In Liaoning province, all sample households with IAB systems chose 8 m^3 biodigesters. These biodigesters utilize human and animal waster (mainly pig manure), and about 70%

of the households also input crop residues into the digester. Details on material inputs and frequencies are shown in Table 5.8.

Table 5.8 Technical Data for Liaoning's "4-in-1" System

	Quantity (kg)	Frequency (cycle in days)	Normalized (kg in 60 day cycle)
Human Waste	21.1	4.3	294.1
Pig Manure	515.8	9.9	3,094.8
Crop Residue	162.0	55.7	172.1

Table 5.9 describes the average initial capital expense for an IAB system (including a greenhouse, a house adjacent to the greenhouse, a digester and other equipment). Survey results revealed that an average of 35,742.0 Yuan is spent for the whole system. The cost of the greenhouse accounts for a large portion (about 85 percent). On the other hand, the cost of the digester accounts for only 5.3 percent of total capital costs.

Table 5.9 IAB Investment Details for Liaoning's "4-in-1" System

	Yuan/household
Total Cost	35,742.0
Greenhouse	30,200.0
House adjacent to greenhouse	3,656.0
Digester (including plumbing, biogas stove, and lighting upgrades)	1,886.0

Access to commercial loans in rural areas of China is very poor. Most investment (96%) in IAB systems in Liaoning is in the form of self-financing, according to survey responses. Households tap their own savings and borrow from friends or relatives. Only 14% of the surveyed farms took loans from local banks (such as the China Agricultural Bank, or China Rural Credit Union). Our survey also found that 46% of IAB system users receive government subsidies for the purchase of their systems. Amounts of self-financing, commercial borrowing and government subsidy are shown in Table 5.10.

Table 5.10 Household Financial Sources for IAB System Purchase (Liaoning Survey)

Financial sources	Yuan/household	% of Households
Self-financing	32,110.4	96
Commercial loan	31,714.3	14
Government Subsidy	6,539.1	46

5.5 Environmental Impacts

Use of IAB systems resulted in several environmental impacts, including reduced fertilizer utilization, lower pest control requires, soil and water quality gains, and human and animal health improvements.

Fertilizer

Respondents to our survey indicate that IAB systems lead to reduced use of synthetic fertilizers, 54% reported lower fertilizer utilization, and 44% reported indicated they required "much less" fertilizer in Liaoning Province.

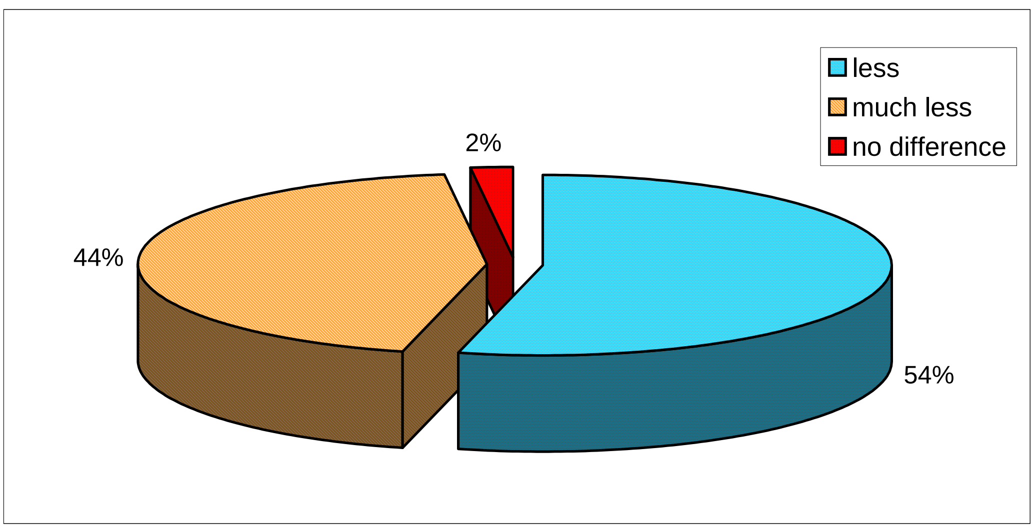


Figure 5.3 Impact of IAB System Use on Fertilizer Utilization in Liaoning

Pest/Insect Control

Regarding pest and insect problems during cultivation, all respondents with IAB systems indicated that such problems have been relieved with installation of the system. 54% reported pest and insect problems were reduced, and 46% reported that they were greatly reduced.

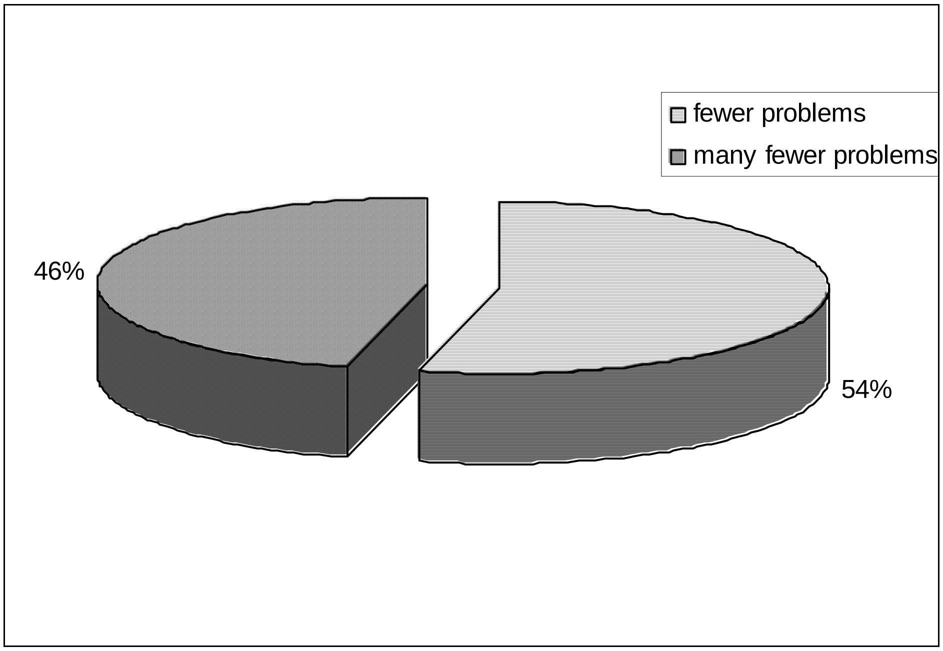


Figure 5.4 Impacts of IAB System Use on Pest/ Insect Problems in Liaoning

Soil/Water Impacts

Respondents report that their IAB systems contribute to improved soil quality. One-half have noticed some level of improvement and the remainder indicate that improvements were substantial. Effects on water quality were less evident, with 64% reporting no appreciable effect.

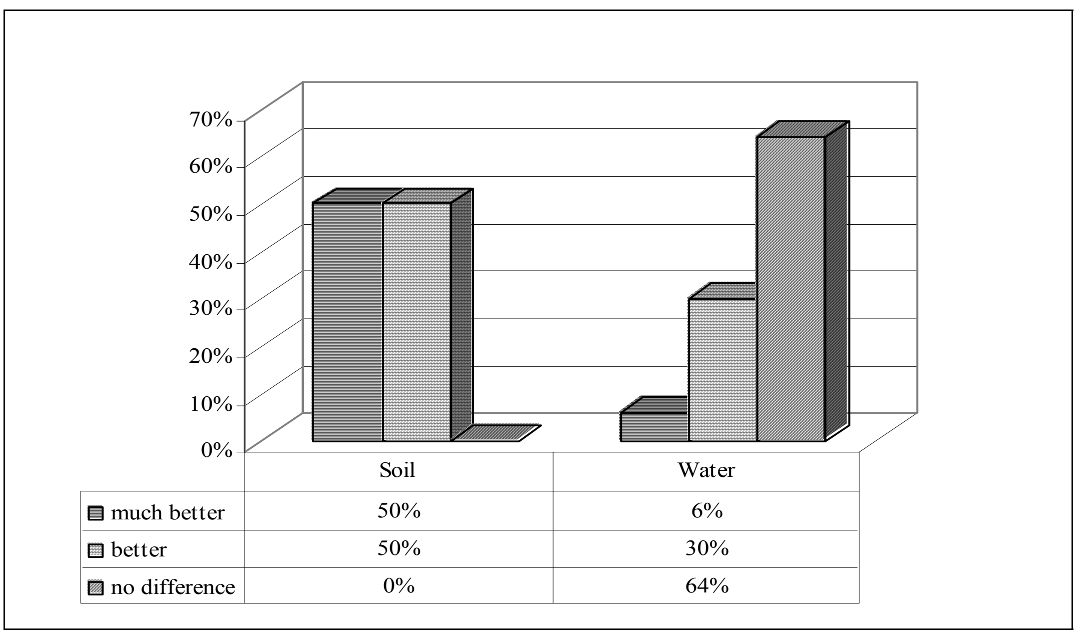


Figure 5.5 Impacts of IAB System Use on Soil and Water in Liaoning

Table 5.11 shows IAB systems in Liaoning can reduce water usage for irrigation from 636 m^3 to 532 m^3 per 1000m^2, which has the collateral benefit of lowering farmers' labor time and expenditures on water.

Table 5.11 Annual Water Usage by Types of Farm System (Liaoning Survey)

	IAB System	CAE System
Water Usage (kg yield/m^3 of water)	7.3	1.1
Total Annual Water Usage (m^3/1000m^2)	532	636

Health Effects

IAB system users repeated significant improvements in animal health with one-half experiencing significant positive effects. This same group found impacts on family health to be less noticeable (but still present). Overall, the family living environment was bettered for most IAB system users (62%).

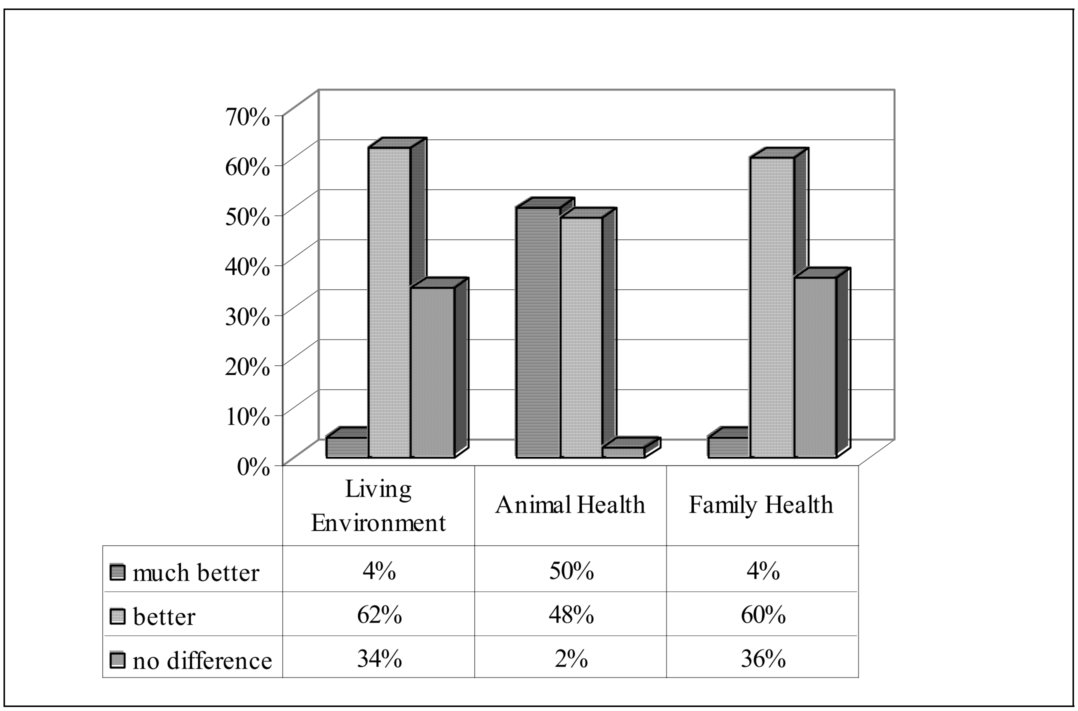


Figure 5.6 Impacts of IAB System Use on Environment and Health in Liaoning

5.6 Policy Preferences

An analysis of policy needs by farmers shows that about half of Liaoning's households with IAB systems rank training assistance on biodigesters as the most important needed action. Further, respondents would like improved access to credit (see Figure 5.7).

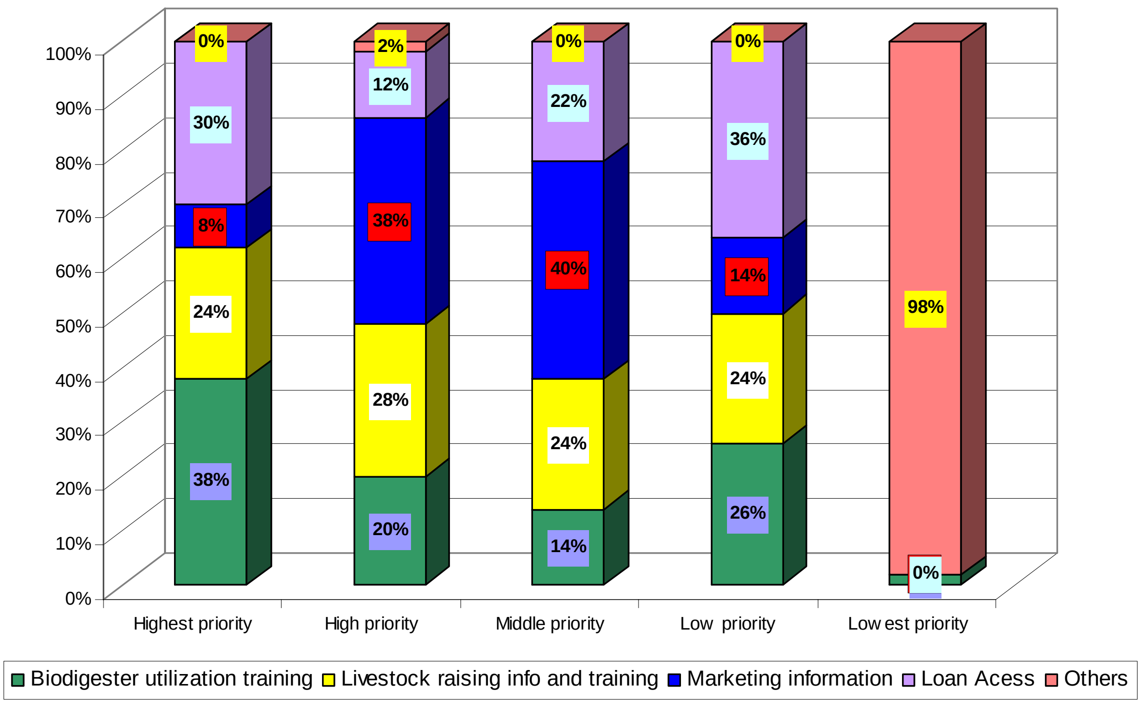


Figure 5.7 Policy Preferences in Liaoning Province

Of the volume of manure and agricultural residues that enter a biodigester, 97-98% can partially be returned as fertilizer spread on farm land (Wang, 2001). But poor operation of the biodigester can greatly reduce this benefit. A professional service (referred to as 'sludge service' below) can be identified to facilitate optimal functioning.

Figure 5.8 represents the survey results regarding farmer attitudes toward the need for an organized sludge service. Our survey asked if respondents would prefer to have professional sludge services for biodigester and over three-quarters indicated they would welcome professional biodigester service companies. This finding suggests that an allied policy need is the promotion of such a service as a rural enterprise. With China's success in developing rural energy service stations (See Byrne et al, 1997) as a model, perhaps this maintenance function can be introduced into the service station model.

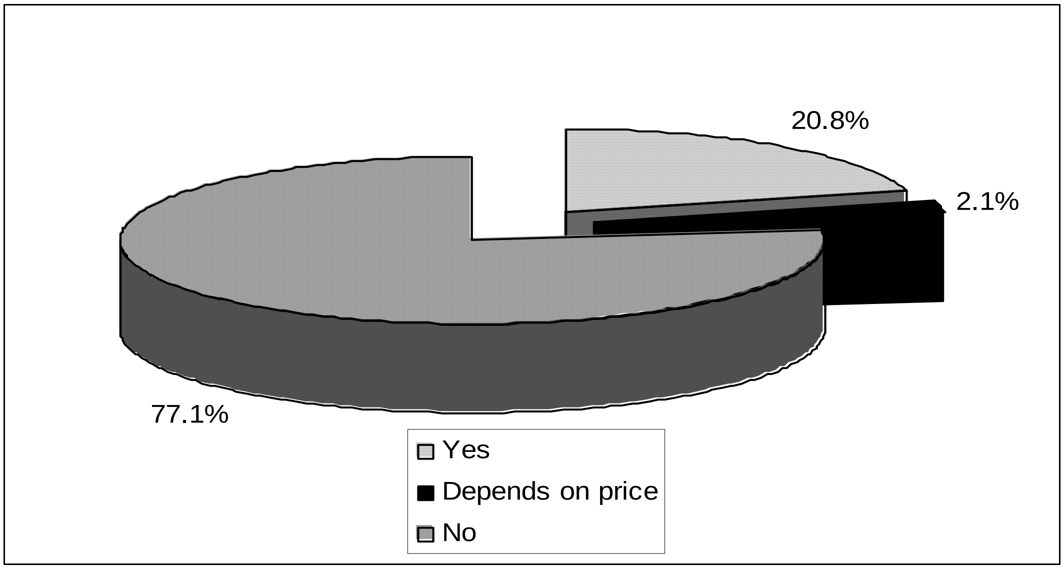


Figure 5.8 The Need for Professional Sludge Service in Liaoning

SECTION 6

Social-Economic Assessment of the IAB Systems in Yunnan

Let us now turn to the survey data from Yunnan Province. Here, the IAB system has only 3 components ─ a biodigester, a pigpen and a home latrine.

6.1 Households Profile – Size, Income, Expenditures and Education

Table 6.1 provides a profile of households in the province using IAB systems compared to those relying on conventional energy sources. On average, households have about 4.3 persons of which 2.4 can serve as farm labor. Households with IAB systems have higher annual incomes (11,117.3 Yuan) compared to those using conventional systems (8,435.3 Yuan). Further, IAB system users have lower annual overall expenditures (5,603.9 Yuan) than those depending on traditional energy sources (5,790.2 Yuan). Accordingly, the former have higher net incomes (4,509.8 Yuan) than traditional farmers (1,622.2 Yuan). These results suggest that the installation of an IAB system significantly increases economic status in Yunnan. The average net per capita income for both user categories, however, remains far below the national average (2,475.6 Yuan).[13]

Table 6.1 Profile of Sampled Households in Yunnan Province

	IAB System Users	CAE System Users
Household Size (Persons)	4.3	4.3
Number Available for Farm Labor (Persons)	2.4	2.4
Average Cultivated Land ($1000m^2$)	5.50 (0.25[14])	5.74
Annual Household Income (Yuan)	11,117.3	8,435.3
Annual Household Expenditure (Yuan)	5,603.9	5,790.2
Net Household Income (Yuan)	5,512.4	2,645.0
Net Income Per Capita (Yuan)	1,281.9	615.2

Table 6.2 shows annual household income, expenditures and net income of households with IAB and CAE systems. Total household expenditures are calculated by summing expenditures for agriculture activities, commercial energy, taxes, insurance and others.

[13] Data source: China Statistical Yearbook, 2003.
[14] Average land size for IAB systems in Yunnan Province.

Farm incomes in Yunnan are lower than those in Liaoning, according to our survey. While Yunnan farmers with IAB systems tend to have higher incomes than conventional energy system users, the difference is not as dramatic as in Liaoning. Miscellaneous expenditures (including expenditures on food, clothing and education, health care and medication) account for most household expenses, regardless of type of energy system used. The second largest source of expenditures is agricultural activities.

Table 6.2 Annual Household Incomes and Expenditures for the Yunnan Survey

Unit: Yuan

	IAB System Users	CAE System Users
Total Household Incomes	**11,117.3**	**8,435.3**
Agricultural sources	8,984.8	6,954.9
Other	2,132.5	1,480.6
Total Household Expenditures	**5,603.9**	**5,790.2**
Agricultural Expenses	2,402.7	1,592.3
IAB system costs	*1,171.0*	*N/A*
Commercial energy	529.0	1,079.9
IAB system costs	*15.8*	*N/A*
Taxes	210.2	219.9
Insurance	357.5	254.0
Other	3,583.7	2,644.2
Net Income	**5,512.4**	**2,645.0**

Yunnan Province has a lower average educational level than Liaoning Province. Most household heads, according to our survey, attended school only at the primary level. No head of household had attended high school or a higher level.

6.2 Agricultural Productivity

Similar to farmers in Liaoning province, most rural households in Yunnan earn income from agricultural activities, including traditional cultivation of cereal, oil-bearing seeds tobacco, vegetables and fruits and domestic animals (mainly hogs). In general, farm households in Yunnan are poorer than farm households in Liaoning, partly due to the mountainous terrain, which results in less productive agricultural land.

Table 6.3 Incomes from Agricultural Activities by Household Type for the Yunnan Survey

Incomes (Yuan)	IAB System Users	CAE System Users
Traditional cultivation (1)	6,739.7	5,814.4
Cultivation within IAB system (2)	658.2	N/A
Of which, from vegetables	*574.5*	*N/A*
Domestic animal and livestock raising (3)	2,221.1	1,291.6
Of which, from hog raising	*1,921.3*	*1,237.2*
Total revenues from agricultural activities =(1)+(2)+(3)[15]	**9,619.0**	**7,106.0**

Note: This table presents results from a survey of 100 households. Average revenue of all households classified by type of energy system is slightly different from the results in Table 6.2 because there are a few cases with missing values for those variables.

Table 6.4 Expenditures incurred in Agricultural Activities by Household Type for the Yunnan Survey

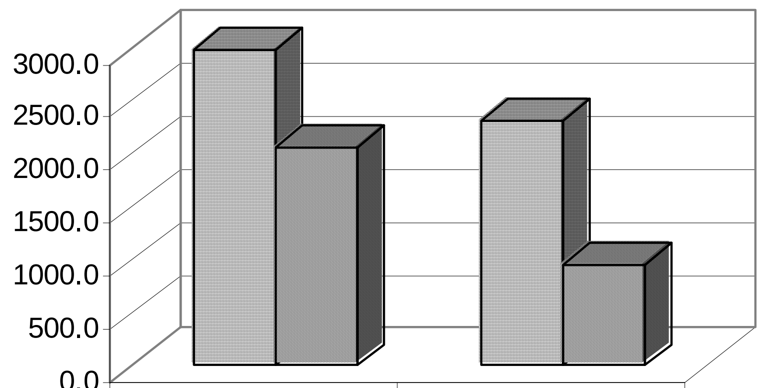
Expenditures (Yuan)	IAB System Users		CAE System Users
		IAB System only	
Seedlings	231.70	52.18	127.14
Commercial fertilizer	747.60	63.18	753.60
Pesticides	177.14	21.47	155.70
Animal feed	581.28	581.28	202.71
Piglets	522.26	522.26	348.45
Plastic (for greenhouse)	N/A	N/A	N/A
Miscellaneous	683.64	0.00	206.40
Total	**2,259.98**	**1,240.36**	**1,587.61**

Note: This table presents results from a survey of 100 households. Average revenue of all households classified by type of energy system is slightly different from the results in Table 6.2 because there are a few cases with missing values for those variables.

Figure 6.1 describes the average unit yield and revenue for vegetables and fruit production per unit of land for households with IAB systems and conventional energy systems in Yunnan. Households with 3-in-1 IAB systems clearly produce larger amounts of vegetables and earn more from their production. In fact, households with IAB systems raise about 44% more vegetables than using those conventional agricultural systems (2985.9 kg/1000m^2 with system vs. 2072.3 kg/1000m^2 with CAE systems). Revenues for IAB system users (2319.8 Yuan/1000m^2 per household annually) are more than twice

[15] Total revenue from agricultural activities is the sum of revenue from (1) traditional cultivation, (2) revenue from cultivation in IAB system and (3) domestic animal and livestock raising.

their counterparts (949.1 Yuan/1000m^2 per household annually). Their differences in vegetable yield and revenue are traceable to the increase in productivity associated with organic fertilizers supplied by the IAB systems.



	Unit Yield (kg/1000SQM)	Net Revenue (Yuan/1000SQM)
IAB System	2985.9	2319.8
TAE System	2072.3	949.1

Figure 6.1 Annual Unit Yield and Revenue from Vegetables by Types of Household Energy System (Yunnan Survey)

The survey also found that farms with 3-in-1 IAB systems used less than Yunnan farming under conventional cultivation. Pollution caused by constant application of excessive chemical fertilizers and pesticides could be alleviated, if an IAB system's organic fertilizer supply were better understood.

In sum, our research found that households with IAB systems in Yunnan earn higher revenues from agricultural activities. Unlike in Liaoning Province, there is no difference in livestock raising since both types of farms use the same procedure to raise hogs and fowl. Farms with CAE systems have incomes (615.2 Yuan) that are lower than the national poverty level (865 Yuan per person[16]).

[16] China's national poverty level is 865 Yuan per person (April, 23, 2004, *Chinese Youth Daily*).

6.3 Energy Consumption

Household Energy Use Mix

Six energy sources — electricity, coal, straw, LPG, fuelwood, and biogas — are consumed in households with IAB systems, while five — all but biogas — are utilized in households with conventional systems. We found that the installation of an IAB system results in several differences in how energy is used in Yunnan. First, households with IAB systems no longer use electricity for cooking. Second, fewer households use coal, straw and LPG for cooking. Third, biogas is substituted for electricity to provide lighting, thereby reducing household use of the latter (see Table 6.5). In short, the availability of biogas from the system significantly affects energy consumption in Yunnan province.

Table 6.5 Household Energy Use by Type of Farm Energy System for the Yunnan Survey (Percent of households using energy sources)

		Electricity	Coal	Straw	LPG	Fuelwood	Biogas
IAB System Users	Lighting	100	0	0	0	0	100
	Cooking	0	22	52	2	34	100
	Heating	4	100	0	0	0	0
	Bathing	0	22	52	2	34	0
	Other	0	0	0	0	0	0
CAE System Users	Lighting	100	0	0	0	0	0
	Cooking	8	94	60	20	2	0
	Heating	2	78	0	0	2	0
	Bathing	0	38	48	0	40	0
	Other	0	0	0	0	0	0

Household Energy Consumption and Expenditure

A comparison of total commercial energy consumption and expenditures among households with IAB and conventional systems shows that all Yunnan farms tend to use less energy than their counterparts in Liaoning. This is partly explained by the lack of cold winters and comparatively low income. As with results reported for Liaoning, biogas is not included in the comparisons in Table 6.6 since it is not purchased in a market. Physical amounts of energy used by farms with IAB systems are less than those relying on conventional systems.

Table 6.6 Household Energy Consumption and Expenditures by Household Type for the Yunnan Survey

		Electricity	Coal	LPG	Fuelwood
IAB System Users	Physical Amount	252.6 kWh	2.2 ton	4.0 tanks	0.90 ton
	Monetary value (Yuan)	109.6	441.8	200.0	360
CAE System Users	Physical Amount	312.7 kWh	4.4 ton	6.3 tanks	1.25 ton
	Monetary value (Yuan)	128.2	907.2	312.8	500

Note: 1 tank of LPG = 15 kg LPG.

Employing the same regression model we did for Liaoning, the regression coefficients estimated for Yunnan appear in Table 6.7.

Table 6.7 Regression Results for the Role of Income and Energy System Type on Household Commercial Energy Demand for Yunnan

Household Energy Demand		**Household Electricity Demand**	
Estimated Coefficient	**Statistical Significance**	**Estimated Coefficient**	**Statistical Significance**
α_0:1097.24	t= 2.61 p<0.006	β_0:68.10	t= 2.39 p<0.011
α_1: -645.49	t= 3.65 p<0.000	β_1:-14.13	t= 1.99 p<0.026
α_2: 0.0369	t= 2.37 p<0.011	β_2: 0.0055	t= 1.73 p<0.045
α_3: -0.0223	t= 2.81 p<0.004	β_3: -0.0017	t= 3.28 p<0.001

Again, it appears that farms with IAB systems will spend less on commercial energy, holding income constant (see α_1); and this is also true for expenditures for electricity (β_1), but the effect is less pronounced.

6.4 IAB System Impacts

Basic Information

Unlike Liaoning, Yunnan is comprised mainly of mountains and plateaus (especially, the Yun-Gui Plateau), and altitudinal and climatic variation is greater. Still, temperatures for farm areas are more moderate than those for Liaoning. As a result, Yunnan's IAB systems lack greenhouses. Normally, a 10-20 m^2 pigpen area is constructed that can raise 3-6 pigs. The system results in energy savings for normal operations, and reduces irrigation requirements. Biogas from the digester substitutes for approximately 40% of commercial energy use for cooking and lighting. The high nutrient value of organic fertilizer taken from digester sludge reduces water requirement by about 26% per 1000 m^2.

Technical and Financial Data

In Yunnan, 40% of sample households with IAB systems chose 6 m^3 biodigesters, the other 60% chose 8 m^3 biodigesters. Only one household in our sample used crop residue in addition to human and pig waste. Two households used other agricultural residues as raw materials in the biodigesters. Details on input amounts and frequencies can be found in Table 6.8.

Table 6.8 IAB Technical Data for Yunnan's "3-in-1" System

	Quantity (kg)	Frequency (cycle in days)	Normalized (60 day cycle)
Human Waste	22.98	3.92	90.08
Pig Manure	346.08	5.42	1,875.75

Table 6.9 describes the average initial capital expense for the installation of an IAB system in Yunnan (including a pigpen, a digester and other equipment). Survey results reveal that an average of 3,484.4 Yuan is required — lower than in Liaoning (due to the absence of a greenhouse), but still a sizable investment for the region's farmers. The bulk of the system's cost is the digester (over 70%).

Table 6.9 IAB Investment Details for Yunnan's "3-in-1" System

	Yuan/household	**Percentage**
Total Cost	3,484.4	100
Pigpen	1,000.0	28.7
Digester & other expenses	2,484.4	71.3

Access to commercial loans appears to be better in Yunnan than Liaoning. Sixty-eight percent of IAB system users in Yunnan borrowed the needed capital from commercial banks, and over 80% received a government subsidy. The remainder of the investment was paid from personal savings (See Table 6.10).

Table 6.10 Household Financial Sources for IAB Systems (Yunnan Survey)

Financial sources	**Yuan/household**	**% of Households**
Self-finance	2,127.4	82
Bank loan	329.8	68
Government Subsidy	1,150.0	84

6.5 Environmental Impacts

Utilization of IAB systems was found to have several environmental impacts. These are discussed below under the categories of fertilizer utilization, pest control, soil and water quality, human and animal health.

Fertilizer Utilization

In Yunnan, only 9 percent of the respondents reported experiencing no difference in fertilizer utilization after an IAB system was installed, while 91 percent reported reduced need for synthetic fertilizer. As with Liaoning's farmers, the organic nutrient provided by the biodigester is found to have significant agricultural value.

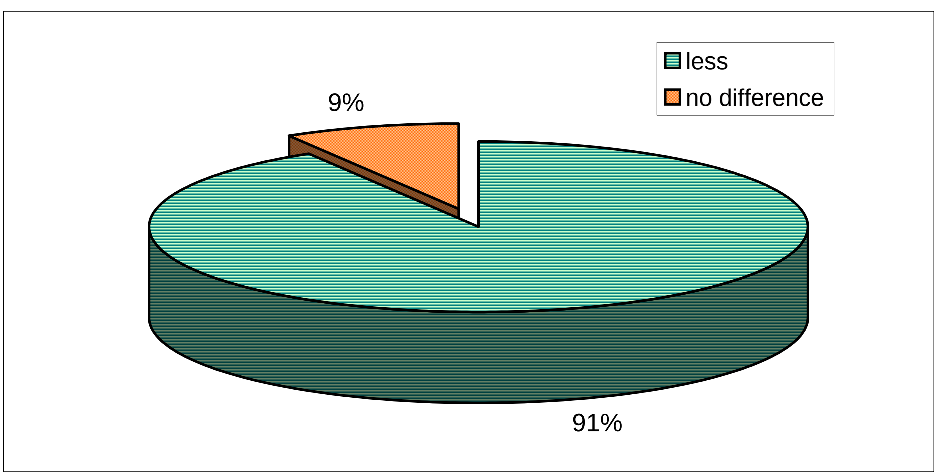


Figure 6.2 Impacts of IAB System Use on Fertilizer Utilization in Yunnan

Pest/Insect Control

As regards pest and insect problems during agricultural cultivation, 78 percent of respondents reported improvements following the installation of an IAB system, while 22 percent reported no difference in this category.

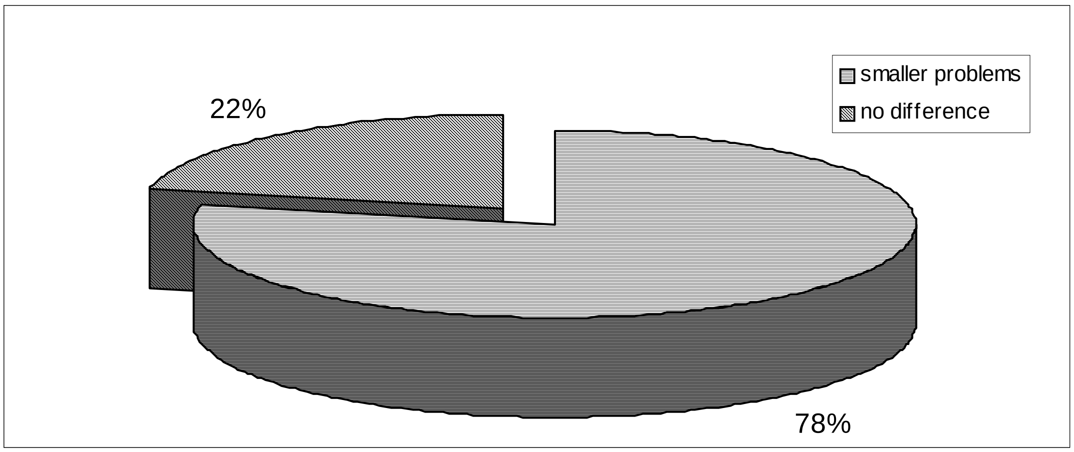


Figure 6.3 Impacts of IAB System Use on Pest/ Insect Problems in Yunnan

Soil/Water Impacts

Yunnan's farmers indicate that their IAB systems have contributed to improved soil quality. Over 60% recognized some level of improvement. Effects on water quality were less evident, with 46% reporting a noticeable improvement.

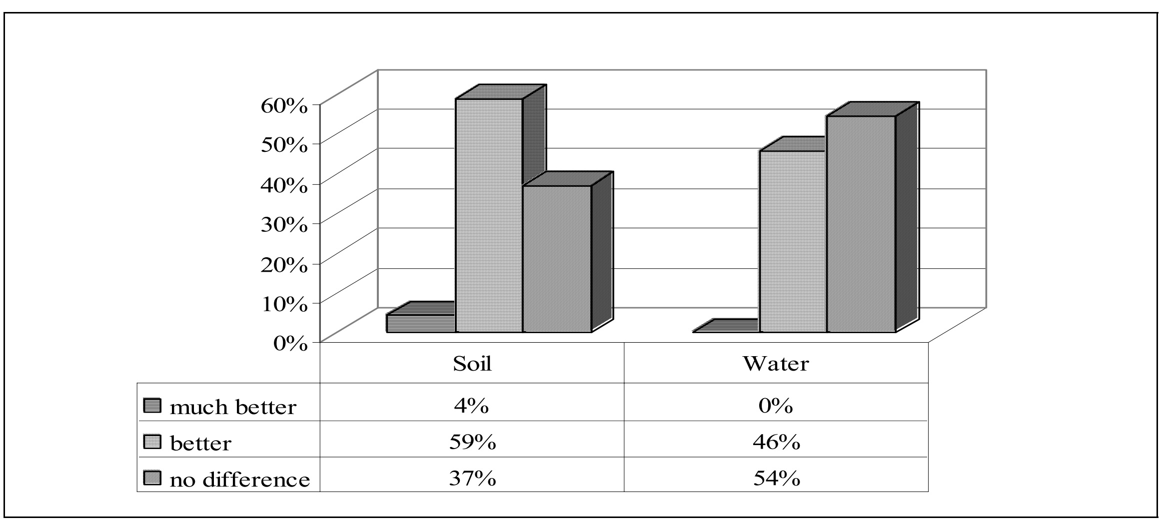


Figure 6.4 Impacts of Environment Quality and Health with IAB System in Yunnan Province

Like IAB systems in Liaoning, Yunnan's systems also reduce water usage for irrigation compared to CAE systems. Water requirements fell by nearly 13%, from 720 m^3 to 631 m^3 per 1000 m^2.

Table 6.11 Annual Water Usage by Types of Farm System (Yunnan Survey)

	IAB System	CAE System
Water Usage (kg yield/m^3 of water)	4.5	0.6
Total Annual Water Usage (m^3/1000m^2)	631	720

<u>Health Impacts</u>

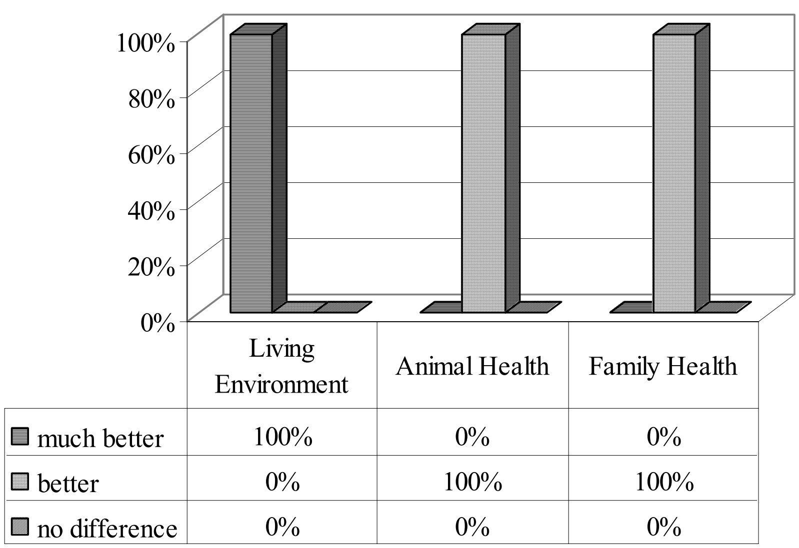


Figure 6.5 Impacts on Environment Quality and Health with IAB System in Yunnan Province

As the above figure illustrates, all IAB system users reported positive effects on living environment, soil, water, animal and family health. In the case of living environment and animal and family health, 100 percent of respondents reported changes as 'better' or 'much better' after the system was installed.

6.6 Policy Preferences

The analysis of policy needs of Yunnan's farmers indicates that about half of those using IAB systems see the need for training assistance on biodigester operation. The respondents also expressed a clear interest in marketing assistance. Training on livestock raising and improved access to loans had a lower priority among Yunnan respondents (Figure 6.6).

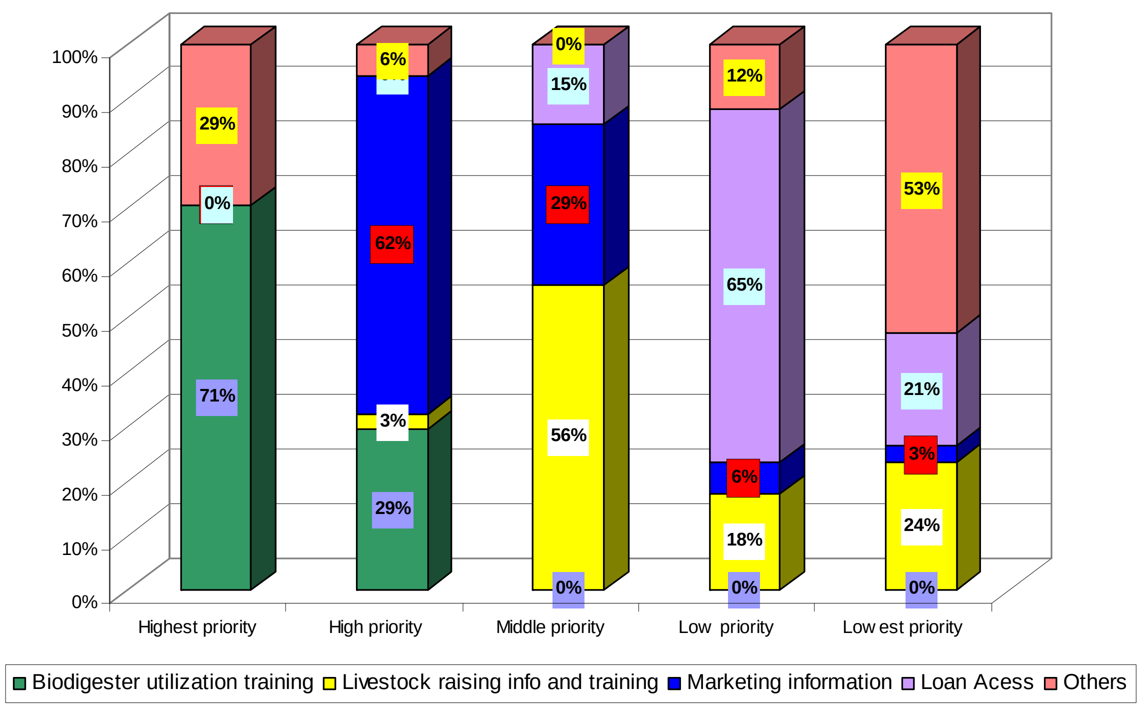


Figure 6.6 Policy Preferences in Yunnan Province

Similar to Liaoning Province, most Yunnan farmers with IAB systems would welcome a well-organized sludge service from biodigester service companies (see Figure 6.7). Less than one in five reported no interest in such a service.

Compared to the significant improvement of rural household incomes in Liaoning province, IAB systems in Yunnan province have had more modest economic impacts. Nonetheless, IAB system users report lower uses of commercial energy, chemical fertilizers and pesticides compared to farmers relying on conventional agricultural system for the area. Furthermore, environmental and health gains are reported. Thus, it appears that the “3-in-1” systems in Yunnan offer an important opportunity to improve agricultural productivity, reduce household energy and health costs, and contribute to better soil and water quality.

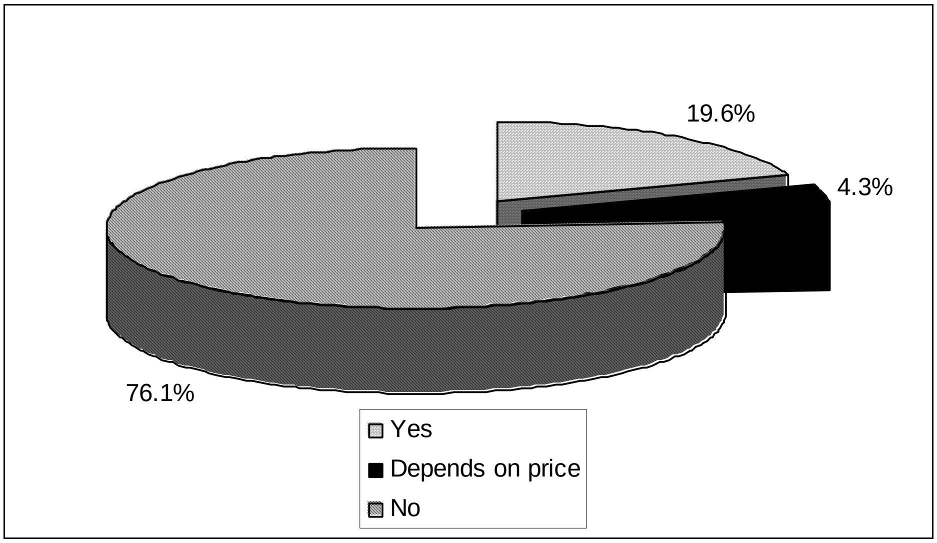


Figure 6.7 The Need for Professional Sludge Service in Yunnan

The survey results suggest the existence of important benefit streams to individual farmers and to society and the environment. But are these benefits measurably significant? In the next section, a quantitative analysis of benefits and costs is undertaken to better define IAB system economics. To accomplish this, the survey data are supplemented with additional information from the research literature in order to build an accurate picture of the full impacts of the IAB strategy.

SECTION 7

Multi-Dimensional Analysis of IAB and CAE Systems

7.1 Introduction

The costs and benefits of IAB systems analyzed in this report will vary by size of the digester, number of pigs raised, type of crops grown, presence or absence of a greenhouse and the price of fodder. Other factors that affect the economic value of IAB vs. CAE based farms are market prices of crops and pigs, costs of energy, irrigation, fertilizer and pesticide, and healthcare[17] and soil impacts. CEEP researchers carried out a multi-dimensional analysis of IAB systems in order to compare their ecological, economic, energy and health effects.

Two farming system scenarios — IAB and CAE — are constructed in which farm size and labor cost are held constant. Several assumptions are made that would permit valid comparisons of the economics of IAB and CAE based farms. Both have the same household size (4 persons). Based on responses to the CEEP-ERI survey, the pigpen area size is set at 20 m^2 in Liaoning and 10 m^2 in Yunnan; farm size is set at 1000 m^2 in Liaoning and 800 m^2 in Yunnan for both IAB and CAE systems (Table 7.1). Annual marketable pig numbers are different for IAB and CAE systems in Liaoning because of the collateral benefits for pig raising of IAB systems (the pigpen is located next to the greenhouse and warmer temperatures during the winter enhance pig growth). Biodigester sizes in IAB systems are set at 8 m^3 (Liaoning) and 6 m^3 (Yunnan), the common models applied in these two provinces according to our survey results. Average daily biogas production is assumed to be 1.5 m^3 and 1.0 m^3 in Liaoning and Yunnan, respectively, due to climate difference between these two provinces.

[17] IAB systems can reduce irrigation requirements, energy demand, fertilizer and pesticide needs, and the need for healthcare visits and expenditures. Prices for these items can be used to estimate household benefits in the form of avoided costs.

Table 7.1 Key Assumptions

	Liaoning		Yunnan	
	IAB System Users	**CAE System Users**	**IAB System Users**	**CAE System Users**
Household				
Number of persons	4	4	4	4
Pigpen				
Area of pigpen (m^2)	20	20	10	10
Number of pigs on hand (heads)	6	3	3	3
Number of pigs sold per year (heads)	6	3	3	3
Biogas digester				
Digester size (m^3)	8	-	6	-
Biogas production per day (m^3)	1.5	-	1.0	-
Land size in system				
Land area in system (m^2)	1000	1000	800	800

Additionally, we assume vegetables are cultivated in the greenhouse on farms served by IAB systems[18]. Common agricultural crops (i.e., grain, oil-bearing or vegetables) in the CAE systems in Liaoning and in both systems in Yunnan. The IAB system includes a biodigester, which has an expected lifetime of 15 years, while the plastic film of the greenhouse (if present) must be replaced annually, and the insulated grass blanket is also assumed to be replaced biannually. Other assumptions and parameters used in our multi-dimensional assessment are: discount rate of 6%, 15 year evaluation period, no salvageable value left after 15 years, all products are sold at market prices, operation and maintenance (O&M) costs are constant over the evaluation period, and all investments occur in the construction period. Values of variables such as O & M costs, market prices, etc., are based upon survey results.

The costs and benefits used in our multi-dimensional analysis are listed in Table 7.2 (See Annex C for details). Survey results, where appropriate, are used to establish financial parameters. Additionally, information from Rural Energy Offices of the two provinces, ERI, the Chinese Ministry of Agriculture, and the research literature are relied upon to

[18] In the case of Yunnan, we assume 70% of crops grown with the aid of "3-in-1" systems are vegetables.

establish appropriate values, including the costs of the grass blanket, water, labor, health care and township and village enterprise (TVE) wages.

Table 7.2 Costs and Benefits in the Multi-Dimensional Analysis (Unit: Yuan)

	Liaoning		*Yunnan*	
	IAB System	**CAE System**	**IAB System**	***CAE System***
Fixed costs				
Greenhouse	25,000	-	-	-
Digester	1,500	-	1,125	-
Latrine	100	-	50	-
Pigpen	400	400	200	*200*
Miscellaneous	110	90	110	*90*
Subtotal	**27,110**	**490**	**1,485**	***290***
Variable costs				
Pig-raising related	2,340	1,200	1,290	*1,290*
Crop related	3,627	649	375	*341*
Labor for pig-raising	1,008	504	378	*378*
Labor for crop cultivation	1,560	600	432	*432*
Labor for digester O&M	136	-	102	-
Labor for TVE	-	1,600	-	*102*
Miscellaneous	595	181	331	*339*
Subtotal	**9,266**	**4,734**	**2908**	***2,882***
Revenue				
Sales of pigs	3,780	1,890	2,250	*2,250*
Sales of crops	29,640	1,875	3,540	*1,241*
TVE wages	-	3,000	-	*170*
Subtotal	***33,420***	***6,765***	***5,790***	***3,661***

For health costs associated with users of CAE systems, we assume a CAE farm needs 8 person days off annually on average due to illness (which could be avoided by adopting an IAB system). The cost is estimated to be 15 Yuan/person day in Liaoning and 12 Yuan/person day in Yunnan.

7.2 Financial Analysis

A comparative economic evaluation of the conventional agricultural energy (CAE) system and the IAB system was performed. This enables an objective determination of the relative economic viability of the IAB system.

Five scenarios are assessed in our analysis: a Baseline Scenario, Scenario A (energy savings included), Scenario B (energy and medical expense savings included), Scenario C (energy and medical expense savings and soil impacts[19] included), and Scenario D (energy and medical expense savings, soil impacts and CO_2 emission reductions included).

If only direct benefits from sales of agricultural products and pigs are included (Baseline scenario, see Tables 7.3 and 7.4), a greater economic value is found for IAB systems. In Liaoning, a farm of constant size and labor input realizes a BCR of 2.63 and return on capital from improved agricultural productivity mean that its higher costs are paid back in two years. By contrast, a farm relying on a CAE system realizes a BCR of only 1.32 and its return on capital results in a 4-year payback period. IAB systems in Yunnan produce a 1.76 BCR and a 3-year payback period, compared to a 1.08 BCR and 11-year payback period for Yunnan farmers using CAE systems.

Table 7.3 Financial Analysis of IAB Systems by Province

Variables	**Liaoning**	**Yunnan**
Capital Cost of IAB System (Yuan)	27,110	1,485
Annual O&M Cost (Yuan)	9,268	2,909
Agricultural & Swine Taxes(Yuan)	98	60
Direct Benefits —sale of pigs (Yuan)	3,780	2,250
— sale of crops (Yuan)	29,640	3,540
NPV (Yuan)	201,116	24,214
BCR	2.63	1.76
Payback Period (Years)	2	3

[19] Soil impacts of IAB and CAE system are different, IAB systems improve soil quality by increasing the thickness of living soil layer (regarded as a benefit) and CAE systems degrade soil quality due to continuous chemical fertilizer application (regarded as a cost).

Table 7.4 Financial Analysis of CAE Systems by Province

Variables	Liaoning	Yunnan
Capital Cost of an CAE System (Yuan)	490	290
Annual O&M Cost (Yuan)	3,138	2,856
Agricultural & Swine Taxes(Yuan)	68	60
Direct Benefits ─sale of pigs (Yuan)	1,890	2,250
─ sale of crops (Yuan)	0	1,241
NPV (Yuan)	15,779	2,727
BCR	1.32	1.08
Payback Period (Years)	4	11

The results of the financial analysis indicate that IAB systems offer greater economic promise for small farms in both provinces. Given the variation in variable values that normally is expected in a BCR analysis, the very low results for Yunnan's farms relying on CAE systems raises concerns about the long-term viability of these farms.

7.3 Environmental and Health Analysis

The principal impacts of a CAE system on environment and health fall into five categories:

- The spread of flies, mosquitoes and other pests and the resulting need for pesticides;
- Contamination of soil, watersheds and underground water as a result of the application of untreated human and animal wastes as fertilizers to farm land;
- Contagious diseases resulting from pests breeding in human and animal waste;
- Energy consumption, greenhouse gas emissions and deforestation (from fuelwood use);
- Soil erosion.

In the case of CAE systems, untreated human and animal waste is often applied to agricultural land as fertilizer in rural China. Pollution of surface and ground water can result, and a breeding environment for flies, mosquitoes and other pests can be created.

Human and animal waste also tends to generate an obnoxious odor in the absence of treatment.

IAB systems treat human and animal waste through anaerobic digestion. The resulting effluent and sludge is a high quality organic fertilizer, rich in humus, which is an ecologically beneficial nutrient. This benefit can be expected to increase over the long term. It is also free of odor, disease pathogens and weed seeds because the process of anaerobic digestion efficiently kills pathogens and parasite eggs. According to research results by ADB (2002), Wang (2001), Gu and Zhang (1997) etc, in combination with CEEP's study, we estimates that IAB users will save an average of 45-60 Yuan per person per year in health care costs, which is equivalent to 0.69% of family income in Liaoning, and 2.03% of family income in Yunnan. The IAB system also produces a high quality source of energy in the form of biogas, which reduces the need for fuelwood, thus helping to preserve forests. Biogas is a clean-burning cooking fuel that can reduce the prevalence of health problems among women and children, especially respiratory and eye problems, associated with indoor fuelwood burning.

The above environmental and health benefits of IAB systems are, however, difficult to quantify (although many researchers have attempted to do so, see Shi, 2002, Ye & Wang et al, 2002 Wang, 2001 Chen,1997).

In addition, according to research by Gu (1999), Zhang(1997) and Williams et al (1996), annually an IAB system is estimated to produce 0.25 Yuan/m^2/cm of soil by increasing topsoil layer thickness, and a CAE loses 0.25 Yuan/m^2/cm of soil due to topsoil erosion over a 15-year evaluation period.

7.4 Analysis of Energy Savings and Greenhouse Gas Reduction Potential

Biogas derived from IAB system operations can substitute for traditional fuels like coal, fuelwood and LPG. Rural families can thereby benefit from reduced energy costs, less labor and time associated with fuelwood collection, and lower cooking time.

Biogas use can also contribute to CO_2 emission reduction when it substitutes for coal, LPG or fuelwood (all of which contain higher carbon concentrations). CO_2 emission factors for each type of energy source can be used in conjunction with percentages of energy consumed (the amount of energy consumed in rural households without IAB systems) in order to calculate CO_2 reductions. The results for Liaoning and Yunnan are shown in Table 7.5.

Table 7.5 Heat Value, Combustion Efficiency, CO_2 Emission Factors and Energy Mix for Households Relying on CAE Systems

	Heat Value	Combustion Efficiency	CO_2 Emission Factors (g/MJ)	Energy Mix for Households with CAE System	
				Liaoning	Yunnan
Biogas	23.03 (MJ/m^3)	57%	81.5	N/A	N/A
Coal	25.12 (MJ/kg)	30%	92.4	5.3%	78.0%
LPG	50.24 (MJ/kg)	54%	67.3	2.5%	0.3%
Fuelwood	13.82 (MJ/kg)	15%	90.7	92.3%	21.7%

On an average, the annual energy savings in the consumption of coal, LPG and fuelwood are 27.5 kg, 3.6kg and 1,753 kg, respectively, for Liaoning Province; and 495.6 kg, 0.60 kg and 501.5 kg for coal, LPG and fuelwood, respectively, in Yunnan Province. CEEP estimates that commercial energy use is decreased by 36% in Liaoning and 58.2% in Yunnan among IAB users (compared to farms relying on conventional energy sources). This translates to annual economic savings of 321 Yuan (US$39) per farm in Liaoning and 308 (US$37) Yuan per farm in Yunnan or a 1.5% and 11.6% increase in family net income in Liaoning and Yunnan, respectively.

Table 7.6 Annual CO_2 Emission Reductions Associated with the Adoption of an IAB System per Rural Household

	Liaoning	Yunnan
National average CO_2 emission for rural households (tons)	3.80	3.68
CO_2 reduction with IAB system (tons)	1.71	1.10

CO_2 emissions could be reduced by 45.0% and 29.9% per farm, respectively, in Liaoning and Yunnan. In the year 2002, there were 279,000 IAB systems in Liaoning, and 804,200 in Yunnan (Tang, 2003; Hu, 2003). As a result, the reduction in total annual CO_2 emissions was 477,090 tons for Liaoning and 884,620 tons for Yunnan. The monetary value of CO_2 emission reductions can be determined by an avoided cost method, which assumes a value for a permit to emit a ton of CO_2 emissions (Byrne et al., 1998). We selected a conservative value of 290 Yuan (US$35) per ton of CO_2 to denote the cost of avoiding CO_2 emissions.[20] Therefore, cost savings from avoided CO_2 emissions for Liaoning and Yunnan are about 138.4 million Yuan and 256.5 million Yuan, respectively.

7.5 Water Impact Analysis

Sludge produced by IAB systems can increase plot yields and, at the same time, reduce the level of irrigation per ton of crop produced (thereby reducing water consumption). The humans in the sludge can also increase the amount of organic complement returned to a farm's soil. This would provide a collateral benefit of increasing the water retention capacity of a farm's soil.

The winter greenhouse, in the case of 4-in-1 systems, can reduce evaporation, thereby lessening water demand per ton of crop produced. In rural areas of China where water is scarce, this supplies an obvious benefit. Thus, IAB systems can offer a practical means for improved water efficiency in agricultural production.

Based upon our survey results, levels of water efficiency improved are quantified in the analysis and proxy values are identified for estimating the economic benefits of such savings. In brief, CEEP concludes that IAB-served farms require 57.5% less water per ton of crop produced in Liaoning and 26.9% less water per ton of crop produced in Yunnan. The economic saving is estimated to be 488 Yuan ($58.8) in Liaoning and 155 Yuan ($18.7) in Yunnan.

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[20] The US$35 figure is based on the average of estimates from five econometric models for 2010 with emissions trading. See Edmonds et al, 1999, page 23.

7.6 BCR Estimates with Selected Social and Environmental Effects Considered

Considering the quantified benefits described above, BCRs can be calculated which capture the social and environmental benefits of IAB system diffusion. These are presented for Liaoning and Yunnan in Table 7.7.

The Baseline Scenario includes only financial benefits and costs. Scenario A adds energy savings from biogas substitution for commercial fuel use. Scenario B includes the energy savings from Scenario A and adds avoided medical expenses, Scenario C adds soil impacts[21] to those in Scenario B. Finally, Scenario D adds the value of CO_2 emission reductions (calculated by the method described in subsection 7.4 above).

Table 7.7 Comparison of Benefit-Cost Ratios with Different Savings by Province

		Scenarios				
		Baseline	A	B	C	D
Liaoning	IAB system	2.63	2.65	2.67	2.67	2.71
	CAE system	1.32	1.32	1.29	1.21	1.21
Yunnan	IAB system	1.76	1.85	1.92	1.92	2.01
	CAE system	1.08	1.08	1.06	0.96	0.96

As indicated in Table 7.7, when the full benefits of IAB systems are included, the BCR for these systems increases in Liaoning from 2.63 to 2.71, and from 1.76 to 2.01 for Yunnan. When long-term adverse health and environmental effects of CAE system use are considered, farms relying on conventional energy sources alone experience a decline in BCRs – from 1.32 to 1.21 in Liaoning and from 1.08 to 0.96 in Yunnan.

[21] Soil impacts of IAB and CAE system are different, IAB systems improve soil quality by increasing the thickness of living soil layer (regarded as a benefit) and CAE systems degrade soil quality due to continuous chemical fertilizer application (regarded as a cost).

7.7 Discussion of Qualitative Benefits

Based upon the CEEP's multi-dimensional analysis, there is little doubt that the IAB system can be an economically viable technology for rural China. We now briefly consider how IAB systems can generate social benefits by strengthening the local economy, contributing to economic growth, creating jobs, and improving sanitary and health conditions. These benefits, while difficult to quantify, surely exist and further substantiate the value of this innovative farm energy strategy pioneered by China.

1). Strengthening the Local Economy

In Liaoning, food production per hectare would increase if IAB systems were in wide use due to an extended growing period resulting from the use of greenhouses in the winter. With the spread of IAB systems, the composition of agricultural products is modified. Vegetable and fruit production would increase and additional markets might develop including the sale of ornamentals (flowers and plants) to urban consumers. For Yunnan, productivity improvement would lift incomes, which have historically been low.

2). Economic Growth

IAB systems increase household incomes from animal raising and vegetable and fruit production. Industries associated with the adoption of IAB systems, such as biodigester construction, food processing (pig-slaughtering, meat processing) and transportation (delivering products to markets) are also likely to benefit. These effects can result in economic "multipliers" in which direct economic gains to farms produce indirect benefits to other sectors. Economic growth is often stimulated as much by indirect effects as by direct income improvements.

3). Rural Job Creation

With the increasing adoption of IAB systems, new jobs would also be created. Annually, each 4-in-1 system (a $1000m^2$ greenhouse and 6 pigs a year) creates 338 person days of agricultural jobs compared to 138 person days in CAE systems,[22] while each 3-in-1 system (800 m^2 orchard or vegetable land and 3 pigs a year) leads to 152 person days of labor versus 135 person days in CAE systems.

4). Sanitation and Health

The adoption of IAB systems can improve community and family sanitary and environmental conditions, which can mean improved lives especially for women and children. As family health gains spread, this can contribute to rural community viability. Healthy children learn better (World Bank, 1999); healthy women contribute more to rural and family economic welfare (World Bank & UNDP, 2000).

7.8 Sensitivity Analysis

From the financial, social and environmental benefits analyses discussed above, it appears that IAB systems will yield high benefits to farms, the society and the natural environment. However, risks associated with the adoption of IAB systems could act as barriers to their adoption by rural households. CEEP researchers conducted a sensitivity analysis in order to determine the degree of risk associated with the adoption of IAB systems. Three factors were taken into consideration for conducting this analysis, namely, revenues, production costs and agricultural taxes. A computation model was built to run the analysis for each variable, with values ranging from a decrease of 20% to an increase of 30%. The results of the sensitivity analysis for Liaoning and Yunnan are presented in Figures 7.1 and 7.2, respectively.

The analysis indicates that the economics of IAB systems as whole are not adversely affected by large changes in revenues, costs or taxes. Variations in revenues and production costs have only modest effects on the BCR. Thus, the purchase of an IAB system appears to pose few risks to rural households.

[22] In China, on average, one laborer cultivates 4000 m^2 (MOA, 2003)

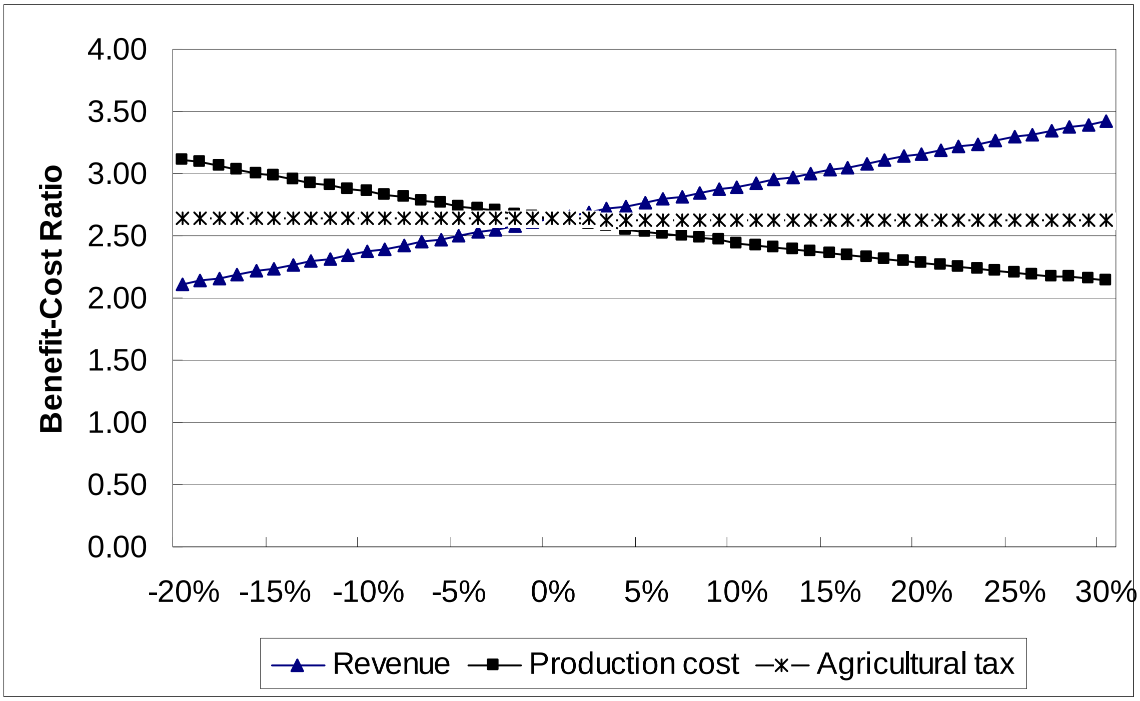

Figure 7.1 Sensitivity Analysis for IAB System Purchase in Liaoning

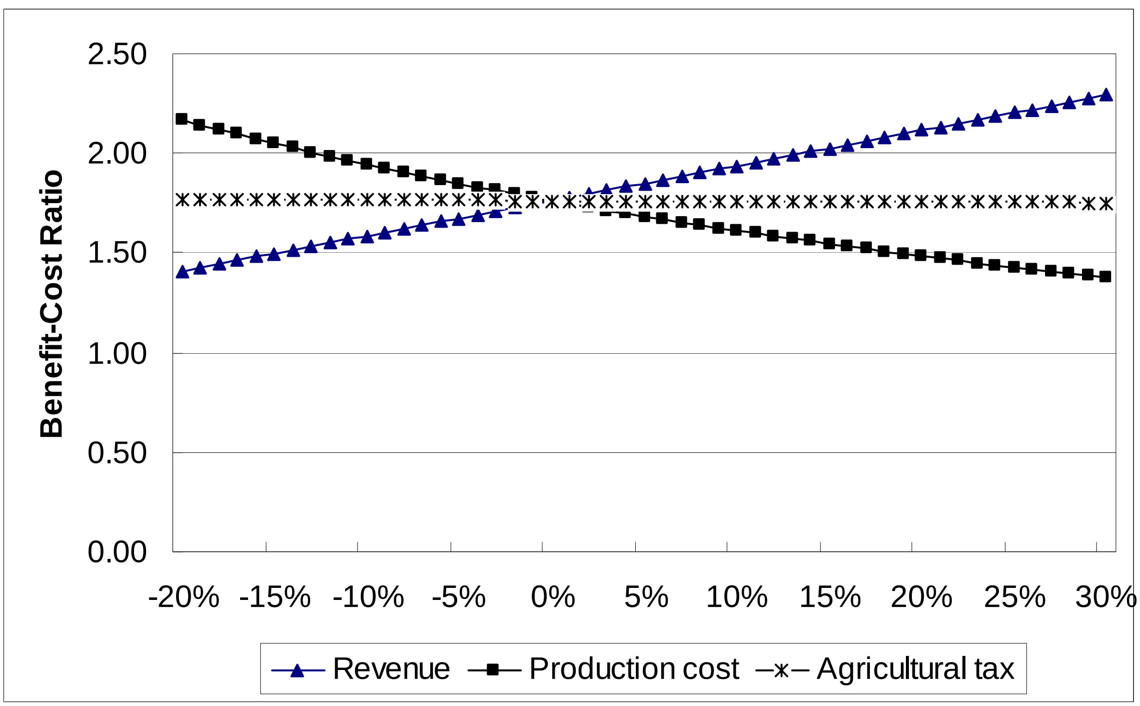

Figure 7.2 Sensitivity Analysis for IAB System Purchase in Yunnan

7.9 Prediction of the Potential Market Size of IAB Systems in Two Provinces and China

Using the official *Outline of China's New and Renewable Energy Development* Program (SETC, 1998), and employing the U.S. Energy Information Administration's National Energy Modelling system (NEMS) (Kydes, 1999), we can estimate the market size of IAB systems by province. The market size of IAB systems in Liaoning, Yunnan and the whole country is presented in Table 7.8. Here, CEEP assumes that the average size of IAB systems in Liaoning and Yunnan are the same as the hypothetical systems analyzed above.

Table 7.8 Market Potential of IAB Systems in Liaoning, Yunnan and China for the Years 2010 and 2020

(Unit: Million Households)

	2002	2010	2020
National	9.200(3.74%)	16.412 (6.68%)	26.044 (10.60%)
Liaoning	0.279 (4.07%)	2.410 (35.14%)	3.405 (49.65%)
Yunnan	0.804 (9.52%)	3.077 (36.42%)	4.509 (53.35%)

Our analysis suggests that in Liaoning, about 50% of rural households could have IAB systems by 2020; in Yunnan, over 50% of farms could purchase IAB systems by 2020. Generally, 11% of rural households nationally could invest in IAB systems by 2020, if policies are adopted that remove barriers to their purchase.

7.10 Conclusions

The diffusion of IAB systems offers an environmentally sound and economically attractive strategy for farm community development. Considering direct benefits from productivity increases alone, the analysis shows that IAB systems in Liaoning promise nearly twice as much income to farms (i.e., a BCR of 2.63 for farms using IAB systems vs. a BCR of 1.32 for those using CAE systems). When selected social and environmental impacts (energy, health, soil impacts and CO_2 emissions) are included, the BCR for farms with IAB systems becomes 2.71 versus 1.21 of CAE system in Liaoning; in the case of Yunnan, the BCR increases to 2.01 versus 0.96 for farms relying on CAE systems.

Given its favorable economics, the potential market size for IAB systems in Liaoning, Yunnan and China as a whole is sizable. We estimate that approximately 26 million rural households might own IAB energy systems by 2020, of which, 3.4 million could be in Liaoning and 4.5 million could be in Yunnan.

SECTION 8

Barriers Analysis and Policy Options for IAB System Development

Our analysis demonstrates IAB systems are economically viable, environmentally sound and contribute to family and public health. Agricultural productivity improves with the use of these systems, which also yield a clean-burning renewable energy, a high quality organic fertilizer and a more sanitary farm operation. However, the promotion and expansion of IAB systems in China faces many barriers and constraints.

8.1 Barriers to IAB System Development and Adoption

The major barriers that restrict the promotion and expansion of IAB systems in Liaoning and Yunnan include the following:

1.) Lack of access to financing and capital in rural areas

In rural China, the Agricultural Bank of China, and rural credit cooperatives are the primary commercial sources of financing services to farmers. However, these banks have been reluctant to provide loans to small farmers (Boxun, 2004).

2.) Lack of skilled IAB system technicians

There is presently a shortage of adequately trained technical staff to install and maintain rural biogas systems. There are only a small number of biodigester system designers, contractors, maintenance technicians, and salespersons. Rapid promotion and expansion of IAB systems in rural China can only be successful if a rural-based personnel infrastructure is built for this purpose.

3.) Lack of markets and distribution systems for agricultural products

The introduction of IAB systems will improve agricultural productivity. However, rural farmers will be unable to effectively reap the economic benefits of this improved productivity, unless markets are organized to absorb increases at prices that cover farm costs and provide a reasonable rate of return. As well, an efficient and speedy distribution system that brings products to markets will be needed.

8.2 Policy Options for IAB System Development

1.) Technical Training and Biogas Technology Service

There is a need for effective training programs, not only for professionals, but also for farmers who will be using IAB systems. From our survey, it is evident that farmers need and would welcome training in system utilization and maintenance, especially biodigester operation. The process of anaerobic digestion is a somewhat complicated one and training is essential if its benefits are to be sustained.

Public funding will be necessary to ensure effective training but local private contractors can conduct the training.

In order to ensure reliable and sustainable operation of IAB systems, a local technical support system is recommended. A Biodigester Service Company (BSCO) can provide training and design services. A BSCO could also provide after-sale O&M services as a step toward creating confidence in the technology among potential users.

2.) Access to Commercial Loans

Although China's financial system has become more commercially oriented in recent years, financial services for farm communities lag behind national experience. Bank branches are needed with trained personnel that can loan and collect funds from farmers. IAB systems are a capital-intensive agriculture technology which can only be afforded with rural finance support. Microfinance programs currently in use in some rural areas of China offer a promising template for investment in IAB systems.

3.) Assistance and Guidance on Agricultural Products Marketing

To ensure timely delivery of agricultural products, there is a need for agricultural brokers that not only distribute products to market, but also collect and disseminate the latest market information to farmers. Brokers can organize a variety of marketing services from township to provincial and national levels. In addition, a “green channel” of transportation providers could break the regional and sectoral monopolies now in place.

4.) Risk Management

After more than 20 years of economic reforms, China has come to a crossroads in the restructuring of its agriculture sector. Recent fee-to-tax reforms have reduced economic burdens on farmers. The trade surplus in the past 5 years is partly due to increased harvests in China which avert the need for food imports. Farmers’ incomes have grown but price volatility creates economic instability even in an otherwise improving environment. It is important to formulate an agricultural insurance system in China to protect farmers’ investments against expectable price fluctuations in any given year.

An insurance plan organized by provincial governments and managed by private companies may be a good strategy to address this issue. Insurance firms would cover unexpected price declines and would thereby incentivize farm commitments to productivity improvement. The current policy strategy in China lacks this feature and may, as a result, retard the diffusion of IAB and other technologies that lift agricultural output.

5.) Education, and Information Dissemination

To increase the rate of adoption of IAB systems, information campaigns that reach farm operators is needed. Survey results indicate that farmers using CAE systems were often unaware of IAB system options and benefits.

8.3 Future Research Needs

China has successfully diffused IAB technology to many of its rural areas. However, the challenges of enlarging the use of IAB systems are several. There are important barriers preventing further commercialization of this technology, as described above. A research effort that monitors policy, market and technology developments would help the country to understand both the opportunities for and obstacles to wider use of IAB options. To take full advantage of a technology in which it is a leader, China should consider the adoption of a sustained research program in bioenergy applications for farm use.

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ANNEX A: SURVEY TEMPLATE FOR IAB SYSTEM IN CHINA

Household ID No.: [ ][ ][ ]

For 4-in-1 System Owner

Date of interview: ____________

Interviewer's Name: ____________

1.1 Province			Q1.1	
1.2 County:			Q1.2	
1.3 Town:			Q1.3	
1.4 Village:			Q1.4	
1.5 Address:			Q1.5	

Section 2: Socio-Economic Information

		Var. Name
2.1	Name of respondent:______________________________	
2.1.1	Sex of the respondent Code: [1] = Male; [2] = Female __________	Q2.1.1
2.1.2	Age of respondent: __________	Q2.1.2
2.1.3	Educational level of respondent: __________ Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education	Q2.1.3
2.1.4	Respondent's relationship to head of household __________ Code: [1] = Head of the household [2] = Head of household's wife or husband [3] = Daughter [4] = Son [5] = Daughter-in-law [6] = Son-in-law [7] = Other, specify	Q2.1.4
2.2	Sex of head of household Code: [1] = Male [2] = Female	Q2.2
2.3	Age of head of household ________ years old	Q2.3
2.4	Age of spouse of head of household _______ years old	Q2.4
2.5	Occupation of head of household Code: [1] = Farmer [2] = Local TVE* worker [3] = Regional TVE worker [4] = Local business manager [5] = Regional business manager [6] = Retired [7] = Other	Q2.5

- TVE means township and village enterprises, a classification of small rural enterprises widely used in China.

		Var Name	
2.6	Educational level of head of household Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education	Q2.6	
2.7	How many persons live in your household for most of the year (2002)? **(Fill in according to age)** **Number of persons on this age**		
2.7.1	Less than 6 years ________	Q2.7.1	
2.7.2	7-18 years ________	Q2.7.2	
2.7.3	19-60 years ________	Q2.7.3	
2.7.4	61 years and over ________	Q2.7.4	
2.7.5	Total ________	Q2.7.5	
2.8	What is the highest educational level obtained by a family member of the household ? (regardless of where he/she lives) Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education	Q2.8	
2.9	How many persons in your household earn income? (include all types of income earned)	Q2.9	

Section 3: Income from Agricultural Activities and Livestock Holdings

		Land Used for Traditional Cultivation (Mu)	Total Yield (Kg)	Net Revenue from Sales (Yuan per Mu)
3.1	**Type of crops planted last year**			
3.1.1	Grains			
		Q3.1.1a	**Q3.1.1b**	**Q3.1.1c**
3.1.2	Oil bearing seeds			
		Q3.1.2a	**Q3.1.2b**	**Q3.1.2c**
3.1.3	Vegetables			
		Q3.1.3a	**Q3.1.3b**	**Q3.1.3c**
3.1.4	Fruits			
		Q3.1.4a	**Q3.1.4b**	**Q3.1.4c**
3.1.5	Flowers			
		Q3.1.5a	**Q3.1.5b**	**Q3.1.5c**
3.1.6	Other commercial crops, (specify………..)			
		Q3.1.6a	**Q3.1.6b**	**Q3.1.6c**
3.1.7	Food crops for family consumption			
		Q3.1.7a	**Q3.1.7b**	**Q3.1.7c**

		Land Used for 4-in-1 (Mu)	Total Yield (Kg)	Net Revenue from Sales (Yuan per Mu)
3.2				
3.2.1	Vegetables			
		Q3.2.1a	**Q3.2.1b**	**Q3.2.1c**
3.2.2	Fruits			
		Q3.2.2a	**Q3.2.2b**	**Q3.2.2c**
3.2.3	Flowers			
		Q3.2.3a	**Q3.2.3b**	**Q3.2.3c**
3.2.4	Other commercial crops, specify			
		Q3.2.4a	**Q3.2.4b**	**Q3.2.4c**

3.3	Land for 4-in-1systems (Mu)	____________	**Q3.3**	
3.4	Land for traditional cultivation	____________	**Q3.4**	
3.5	Total land (Mu)	____________	**Q3.5**	

3.6 **Total number of livestock & domestic fowl currently owned by the family, number sold last year and sale price per animal**

	Total # Owned Currently	# Raised in 4-in-1 Facilities*	Total # Sold Last Year	# Sold from 4-in-1 Facilities	Sale Price Per Animals Sold Last Year (Yuan)
3.6.1 Pigs					
	Q3.6.1a	**Q3.6.1b**	**Q3.6.1c**	**Q3.6.1d**	**Q3.6.1e**
3.6.2 Chickens					
	Q3.6.2a	**Q3.6.2b**	**Q3.6.2c**	**Q3.6.2d**	**Q3.6.2e**
3.6.3 Others, please specify					
	Q3.6.3a	**Q3.6.3b**	**Q3.6.3c**	**Q3.6.3d**	**Q3.6.3e**

* Facilities include pig pens, chicken houses and other building that are part of the 4-in-1 system.

Section 4: Total Household Income and Expenditures

		Var. Name	Total Income Last Year
4.1	**Source of household income**		
4.1.1	Income from agriculture	**Q4.1.1**	
4.1.2	Income from TVE work	**Q4.1.2**	
4.1.3	Gov't subsidy	**Q4.1.3**	
4.1.4	Remittance from relatives	**Q4.1.4**	
4.1.5	Other cash income	**Q4.1.5**	
4.1.6	**Total household income last year**	**Q4.1.6**	

4.2 **Total Annual Household Expenditures (last year)**

		Unit Price	Amo _unt	Total Expendi _ture	Proportion used in 4-in-1
4.2.1	Annual expenditure for seedlings			**Q4.2.1a**	**Q4.2.1b**
4.2.2	Annual expenditure for commercial fertilizer			**Q4.2.2a**	**Q4.2.2b**
4.2.3	Annual expenditure for pesticides			**Q4.2.3a**	**Q4.2.3b**
4.2.4	Annual expenditure for animal feed			**Q4.2.4a**	**Q4.2.4b**
4.2.5	Annual expenditure for piglets			**Q4.2.5a**	**Q4.2.5b**
4.2.6	Annual expenditure on fuel for farming equipment – if any			**Q4.2.6a**	**Q4.2.6b**
4.2.7	Annual expenditure on repairs for farming equipment – if any			**Q4.2.7a**	**Q4.2.7b**
4.2.8	Annual expenditure on plastic for the greenhouse			**Q4.2.8a**	**Q4.2.8b**
4.2.9	Annual expenditure for other agricultural activities			**Q4.2.9a**	**Q4.2.9b**
4.2.10	**Total annual expenditure for agriculture (last year)**			**Q4.2.10a**	**Q4.2.10b**

4.3	**Annual Expenditure for Energy**	**Unit price**		**Monthly Consum_ption**	**Total Expendi_ture**	**Proportion used in 4-in-1**
4.3.1	Electricity	________	Yuan /kwh	________		
					Q4.3.1a	**Q4.3.1b**
4.3.2	Coal	________	Yuan /ton	________		
					Q4.3.2a	**Q4.3.2b**
4.3.3	Fuelwood	________	Yuan /jing	________		
					Q4.3.3a	**Q4.3.3b**
4.3.4	LPG	________	Yuan /tank	________		
					Q4.3.4a	**Q4.3.4b**
4.3.5	The other, (specify………)	________		________		
					Q4.3.5a	**Q4.3.5b**
4.3.6	**Total expenditure for energy (cooking, lighting, heating)**					
					Q4.3.6a	**Q4.3.6b**

Please select the energy sources used in your family (marked with √)

		Electricity	**Coal**	**Straw**	**LPG**	**Fuelwood**	**Other (specify)**
4.3.7	**Cooking**						
		Q4.3.7a	**Q4.3.7b**	**Q4.3.7c**	**Q4.3.7d**	**Q4.3.7e**	**Q4.3.7f**
4.3.8	**Heating**						
		Q4.3.8a	**Q4.3.8b**	**Q4.3.8c**	**Q4.3.8d**	**Q4.3.8e**	**Q4.3.8f**
4.3.9	**Bathing**						
		Q4.3.9a	**Q4.3.9b**	**Q4.3.9c**	**Q4.3.9d**	**Q4.3.9e**	**Q4.3.9f**
4.3.10	**Other (specify)**						
		Q4.3.10a	**Q4.3.10b**	**Q4.3.10c**	**Q4.3.10d**	**Q4.3.10e**	**Q4.3.10f**

4.4	**Total Annual Expenditure for Health Care and Medication**			**Q4.4**	
4.5	**Taxes**				
4.5.1	Agricultural tax	________	**Yuan/Mu**	**Q4.5.1**	
4.5.2	Agricultural specialty tax	________	**Yuan/Mu**	**Q4.5.2**	
4.5.3	Village Administration Fee	________	**Yuan/person**	**Q4.5.3**	
4.5.4	Income tax			**Q4.5.4**	

4.5.5	Other (specify….)		**Q4.5.5**	
4.5.6	**Total annual expenditure for taxes**		**Q4.5.6**	
4.6	**Insurance**			
4.6.1	Health insurance	____________	**Q4.6.1**	
4.6.2	Home property insurance	____________	**Q4.6.2**	
4.6.3	Other (specify….)	____________	**Q4.6.3**	
4.6.4	**Total annual expenditure for insurance**	____________	**Q4.6.4**	
4.7	Other expenditures	____________	**Q4.7**	
4.8	Total annual household expenditures	____________	**Q4.8**	

Section 5: "4-in-1" System

5.1 **Financial Questions**

5.1.1	How much was the initial capital investment for your "4-in-1" system? (in Yuan) __________ Yuan	**Q5.1.1**	
5.1.2	Do you annually invest additional capital in your "4-in-1" system. [0] Yes; [1] No.	**Q5.1.2**	
5.1.3	If yes, how much (Yuan)?	**Q5.1.3**	
5.1.4	How much is the initial capital investment on the greenhouse (Yuan)?	**Q5.1.4**	
5.1.5	What is the cost for the house adjacent to the 4-in-1 system? (Yuan)	**Q5.1.5**	

5.1.6 Financial sources and amount of your investment

		Source (mark with √)	Amount (Yuan)
5.1.6.1	Self		
		Q5.1.6.1.a	**Q5.1.6.1.b**
5.1.6.2	Bank		
		Q5.1.6.2.a	**Q5.1.6.2.b**
5.1.6.3	Government subsidy		
		Q5.1.6.3.a	**Q5.1.6.3.b**
5.1.6.4	Other (specify)		
		Q5.1.6.4.a	**Q5.1.6.4.b**

If there is no financial aid from banks, please go to Question 5.2

5.1.7	Which bank provides the loan for your system? [0] = Chinese Agriculture Bank [1]= Local Credit Union [2]=Other (specify)	**Q5.1.7**	
5.1.8	What is the interest rate on your loan?	**Q5.1.8**	
5.1.9	How much equity is required?	**Q5.1.9**	
5.1.10	Have to pay _________ Yuan per month.	**Q5.1.10**	

5.2 **Technical Questions**

5.2.1 What is the size of the biogas digester in your "4-in-1" system (m^3)?

Q5.2.1	

5.2.2 **What kind of materials do you input to the digester?**

		Any Feed	**Quantity (kg)**	**Frequency (days)**
5.2.2.1	Human waste			
		Q5.2.2.1a	**Q5.2.2.1b**	**Q5.2.2.1c**
5.2.2.2	Pig manure			
		Q5.2.2.2a	**Q5.2.2.2b**	**Q5.2.2.2c**
5.2.2.3	Crop residue-straw&stalk			
		Q5.2.2.3a	**Q5.2.2.3b**	**Q5.2.2.3c**
5.2.2.4	Other agriculture waste (specify …….)			
		Q5.2.2.4a	**Q5.2.2.4b**	**Q5.2.2.4c**

5.2.3 **How much sludge do you take out from the digester**

		Frequency (days)	**Amount**
5.2.3.1	Biogas (m^3)		
		Q5.2.3.1a	**Q5.2.3.1b**
5.2.3.2	Liquid (Dan)		
		Q5.2.3.2a	**Q5.2.3.2b**
5.2.3.3	Solid (Dan)		
		Q5.2.3.3a	**Q5.2.3.3b**
5.2.3.4	Mixed (m^3)		
		Q5.2.3.4	**Q5.2.3.4b**

5.2.4	What is the average temperature inside the greenhouse in the winter ?________ °C	**Q5.2.4**	
5.2.5	What is the area size of the greenhouse in the "4-in-1" system? ________ Mu	**Q5.2.5**	
5.2.6	What is the area size of the pig pen? ________ m^2	**Q5.2.6**	
5.2.7	How many pigs do you sell a year?	**Q5.2.7**	
5.2.8	What percentage of biogas generated by the 4-in-1 system is used to heat the greenhouse?	**Q5.2.8**	
5.2.9	What percentage of biogas generated by the 4-in-1 system is used for family cooking?	**Q5.2.9**	
5.2.10	Unit price of plastic	**Q5.2.10**	
5.2.11	How often does plastic on greenhouse need replacement	**Q5.2.11**	

5.3 **Environmental Impact**

5.3.1 What have been the major environmental impacts of the 4-in-1 system:

5.3.1.1 Fertilizer utilization :
[0] much more;
[1] more;
[2] less;
[3] much less;
[4] no difference ;

Q5.3.1.1

5.3.1.2 Pest/insect problems
[0] very greater problems;
[1] greater problems;
[2] smaller problems;
[3] very smaller problems
[4] no difference ;

Q5.3.1.2

5.3.2 Do you think the living environment is better with 4-in-1 or not?
[0] much better;
[1] better;
[2] worse;
[3] much worse;
[4] no difference

Q5.3.2

5.3.3 Do you think that the quality of the soil on your property has improved due to the 4-in-1 system?
[0] much better;
[1] better;
[2] worse;
[3] much worse;
[4] no difference

Q5.3.3

5.3.4 If possible please explain specifically.

Q5.3.4

5.3.5 Do you think that water quality has improved due to the 4-in-1 system?
[0] much better;
[1] better;
[2] worse;
[3] much worse;
[4] no difference

Q5.3.5

5.3.6 If possible, please explain specifically.

Q5.3.6

5.3.7 Do you think that animal health has improved due to the 4-in-1 system? **Q5.3.7**
[0] much better;
[1] better;
[2] worse;
[3] much worse;
[4] no difference

5.3.8 If possible， please explain specifically. **Q5.3.8**

5.4 **Social/Health Impacts**

5.4.1 Do you think that the 4-in-1 system has improved family health? **Q5.4.1**
[0] much better;
[1] better;
[2] worse;
[3] much worse;
[4] no difference

5.4.2 If possible, please explain specifically. **Q5.4.2**

5.5 **Policy Needs**

5.5.1 What kind of government assistance do you require for the 4-in-1 system? (Mark 1, 2, 3,4 in the priority) **Q5.5.1**

Biogas digester utilization training

Livestock raising information and training

Produces marketing guide

Get loan from banks

Other (specify……)

5.5.2 Would you like to have special companies get the sludge out of the digester? **Q5.5.2**

[0]= Yes
[1]=Depend on the price
[2]=No
[3]=Other(specify)

5.5.3 If yes, how much would you like to pay? (Yuan) **Q5.5.3**

Section 6 General Information

6.1 How much water is applied by irrigation in the greenhouse for each turn (m^3)? ________ **Q6.1**

6.2 How many turns each year? ________ **Q6.2**

ANNEX B: SURVEY TEMPLATE FOR NON-IAB SYSTEM IN CHINA

Household ID No.: | | |

For Non-4-in-1 System Owner

Date of interview: ____________

Interviewer's Name: ____________

1.1 Province	____________		Q1.1	
1.2 County:	____________		Q1.2	
1.3 Town:	____________		Q1.3	
1.4 Village:	____________		Q1.4	
1.5 Address:	____________		Q1.5	

Section 2: Socio-Economic Information

			Var. Name
2.1	Name of respondent:______________________________		
2.1.1	Sex of the respondent Code: [1] = Male; [2] = Female	__________	Q2.1.1
2.1.2	Age of respondent:	__________	Q2.1.2
2.1.3	Educational level of respondent: Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education	__________	Q2.1.3
2.1.4	Respondent's relationship to head of household Code: [1] = Head of the household [2] = Head of household's wife or husband [3] = Daughter [4] = Son [5] = Daughter-in-law [6] = Son-in-law [7] = Other, specify	__________	Q2.1.4
2.2	Sex of head of household Code: [1] = Male [2] = Female		Q2.2
2.3	Age of head of household ________ years old		Q2.3
2.4	Age of spouse of head of household _______ years old		Q2.4
2.5	Occupation of head of household Code: [1] = Farmer [2] = Local TVE* worker [3] = Regional TVE worker [4] = Local business manager [5] = Regional business manager [6] = Retired [7] = Other		Q2.5

* TVE means township and village enterprises, a classification of small rural enterprises widely used in China.

			Var Name	
2.6	Educational level of head of household Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education		**Q2.6**	
2.7	How many persons live in your household for most of the year (2002)? **(Fill in according to age)**	**Number of persons on this age**		
2.7.1	Less than 6 years	________	**Q2.7.1**	
2.7.2	7-18 years	________	**Q2.7.2**	
2.7.3	19-60 years	________	**Q2.7.3**	
2.7.4	61 years and over	________	**Q2.7.4**	
2.7.5	Total	________	**Q2.7.5**	
2.8	What is the highest educational level obtained by a family member of the household ? (regardless of where he/she lives) Code: [0] = No formal schooling [1] = Primary school [2] = Junior high school [3] = Senior high school [4] = Vocational high school [5] = College or university education [6] = Post-graduate education		**Q2.8**	
2.9	How many persons in your household earn income? (include all types of income earned)		**Q2.9**	

Section 3: Income from Agricultural Activities and Livestock Holdings

		Land Used for Traditional Cultivation (Mu)	Total Yield (Kg)	Net Revenue from Sales (Yuan per Mu)
3.1	**Type of crops planted last year**			
3.1.1	Grains			
		Q3.1.1a	**Q3.1.1b**	**Q3.1.1c**
3.1.2	Oil bearing seeds			
		Q3.1.2a	**Q3.1.2b**	**Q3.1.2c**
3.1.3	Vegetables			
		Q3.1.3a	**Q3.1.3b**	**Q3.1.3c**
3.1.4	Fruits			
		Q3.1.4a	**Q3.1.4b**	**Q3.1.4c**
3.1.5	Flowers			
		Q3.1.5a	**Q3.1.5b**	**Q3.1.5c**
3.1.6	Other commercial crops, (specify………..)			
		Q3.1.6a	**Q3.1.6b**	**Q3.1.6c**
3.1.7	Food crops for family consumption			
		Q3.1.7a	**Q3.1.7b**	**Q3.1.7c**

3.2 **Total number of livestock & domestic fowl currently owned by the family, number sold last year and sale price per animal**

		Total # Owned Currently	Total # Sold Last Year	Sale Price Per Animals Sold Last Year (Yuan)
3.2.1	Pigs			
		Q3.2.1a	**Q3.2.1b**	**Q3.2.1c**
3.2.2	Chickens			
		Q3.2.2a	**Q3.2.2b**	**Q3.2.2c**
3.2.3	Others, please specify			
		Q3.2.2a	**Q3.2.2c**	**Q3.2.3c**

Section 4: Total Household Income and Expenditures

		Var. Name	Total Income Last Year
4.1	**Source of household income**		
4.1.1	Income from agriculture	**Q4.1.1**	
4.1.2	Income from TVE work	**Q4.1.2**	
4.1.3	Gov't subsidy	**Q4.1.3**	
4.1.4	Remittance from relatives	**Q4.1.4**	
4.1.5	Other cash income	**Q4.1.5**	
4.1.6	**Total household income last year**	**Q4.1.6**	

		Unit Price	Amo _unt	Total Expenditure
4.2	**Total Annual Household Expenditures (last year)**			
4.2.1	Annual expenditure for seedlings			**Q4.2.1**
4.2.2	Annual expenditure for commercial fertilizer			**Q4.2.2**
4.2.3	Annual expenditure for pesticides			**Q4.2.3**
4.2.4	Annual expenditure for animal feed			**Q4.2.4**
4.2.5	Annual expenditure for piglets			**Q4.2.5**
4.2.6	Annual expenditure on fuel for farming equipment – if any			**Q4.2.6**
4.2.7	Annual expenditure on repairs for farming equipment – if any			**Q4.2.7**
4.2.8	Annual expenditure on plastic for the greenhouse			**Q4.2.8**
4.2.9	Annual expenditure for other agricultural activities			**Q4.2.9**
4.2.10	**Total annual expenditure for agriculture (last year)**			**Q4.2.10**

4.3	**Annual expenditure for energy**				
		Unit price		**Monthly Consum_ption**	**Total Expenditure**
4.3.1	Electricity	__________	Yuan /kwh		
					Q4.3.1
4.3.2	Coal	__________	Yuan /ton		
					Q4.3.2
4.3.3	Fuelwood	__________	Yuan /jing		
					Q4.3.3
4.3.4	LPG	__________	Yuan /tank		
					Q4.3.4
4.3.5	The other, (specify………)	__________			
					Q4.3.5
4.3.6	**Total Expenditure for Energy (cooking, lighting, heating)**				
					Q4.3.6

Please select the energy sources used in your family (marked with √)

		Electricity	Coal	Straw	LPG	Fuelwood	Other (specify)
4.3.7	**Cooking**						
		Q4.3.7a	**Q4.3.7b**	**Q4.3.7c**	**Q4.3.7d**	**Q4.3.7e**	**Q4.3.7f**
4.3.8	**Heating**						
		Q4.3.8a	**Q4.3.8b**	**Q4.3.8c**	**Q4.3.8d**	**Q4.3.8e**	**Q4.3.8f**
4.3.9	**Bathing**						
		Q4.3.9a	**Q4.3.9b**	**Q4.3.9c**	**Q4.3.9d**	**Q4.3.9e**	**Q4.3.9f**
4.3.10	**Other (specify)**						
		Q4.3.10a	**Q4.3.10b**	**Q4.3.10c**	**Q4.3.10d**	**Q4.3.10e**	**Q4.3.10f**

4.4	**Total annual expenditure for health care and medication**			**Q4.4**	
4.5	**Taxes**				
4.5.1	Agricultural tax	__________	**Yuan/Mu**	**Q4.5.1**	
4.5.2	Agricultural specialty tax	__________	**Yuan/Mu**	**Q4.5.2**	
4.5.3	Village Administration Fee	__________	**Yuan/person**	**Q4.5.3**	
4.5.4	Income tax			**Q4.5.4**	

4.5.5	Other (specify….)		**Q4.5.5**	
4.5.6	**Total Annual expenditure for taxes**		**Q4.5.6**	
4.6	**Insurance**			
4.6.1	Health insurance	________	**Q4.6.1**	
4.6.2	Home property insurance	________	**Q4.6.2**	
4.6.3	Other (specify….)	________	**Q4.6.3**	
4.6.4	**Total annual expenditure for insurance**	________	**Q4.6.4**	
4.7	Other expenditures	________	**Q4.7**	
4.8	Total annual household expenditures	________	**Q4.8**	

Section 5 General Information

5.1	How much water is applied by irrigation per Mu for each turn (m^3)?	________	**Q5.1**	
5.2	How many turns each year?	________	**Q5.2**	
5.3	Do you intend to purchasing your own "4-in-1" system in the future? [1]=Yes; [2]=No;	________	**Q5.3**	
5.4	If no, what are the your reasons for not purchasing a "4-in-1" system? [1] Costs too much [2] Too complicated [3] Do not know about the system [4] Cannot get a loan to buy a system [5] Other, specify …….	________	**Q5.4**	

ANNEX C: COSTS AND BENEFITS USED IN THE MULTI-DIMENSIONAL ANALYSIS

Costs Used in the Analysis

	Liaoning		Yunnan	
	IAB System	CAE System	IAB System	CAE System
Fixed costs				
Greenhouse (Yuan/m^2)	20	-	-	-
Latrine(Yuan/unit)	100	-	50	-
Pigpen (Yuan/unit)	400	400	200	200
8 m^3 digester (Yuan/unit)	1,500	-	1,125	-
Accessories (Yuan/system)	90	-	90	-
Variable costs				
Pig-raising				
Feeder pig price (Yuan/head)	140	140	170	170
Feed pigs (heads/year)	6	3	3	3
Animal Feed[23] (Yuan/head)	250	260	260	260
Others cost (Yuan/head)	40	40	40	40
Cultivation				
Rotations each year	2	1	2	2
Seedlings (Yuna/m^2/rotation)	0.21	0.20	0.14	0.08
Fertilizer (Yuan/m^2/rotation)	0.11	0.21	0.04	0.06
Pesticides (Yuan/ m^2/rotation)	0.04	0.11	0.02	0.03
Plastic film (Yuan/ m^2/year)	1.65	-	-	-
Grass Blanket (Yuan/m^2/year)	1.20	-	-	-
Water cost (Yuan/m^3)	0.20	0.20	0.12	0.12
Others (Yuan/m^2/year)	0.89	0.18	0.28	0.36
Labor Input				
Labor cost (Yuan/person.day)	8	8	6	6
Labor required by system[24]				
For agriculture production (person.day/m^2/rotation)	0.098	0.075	0.045	0.045
For pig-raising (person.day/head)	21	21	21	21
For biodigester O&M[25] (person.day/unit)	17	-	17	-

[23] Only about 10% of the feed is grain, protein meal, and premixes. The rest is comprised of food residues available at no cost. Some grain is also fed at the early and late stages of growth (based on interviews concluded by CEEP and ERI staff with local farmers in July, 2003).

[24] Yang Suwei, 2003.

[25] www.biogas-cn.com/cqzs/cqcs.com

Benefits Used in the Analysis

	Liaoning		Yunnan	
	IAB System	**CAE System**	**IAB System**	**CAE System**
Benefits				
Pig-raising				
Market price (Yuan/head)	630	630	750	750
Marketable pigs (head/year)	6	3	3	3
Cultivation				
Sale of crops (Yuan/m^2/rotation)	14.82	1.88	2.21	0.78
Incomes from TVEs				
Wages from TVEs (Yuan/person. day)	-	15	-	12
Energy, Health and Environmental				
Energy savings (Yuan/year)	308	-	321	-
Health Impacts-medical expenditure savings (Yuan/person/year)	52.5	-	52.5	-
CO_2 reduction (ton/year)	1.71	-	1.10	-
Avoided cost of CO_2 emission (Yuan/ton)	290	-	290	-
Annual soil impacts (Yuan/m^2/cm topsoil lose or increase)	0.25	-0.25	0.25	-0.25