Chapter 4 A CDM Project of Livestock Waste Management System: A Case Study in Dingcheng, Changde City, Hunan Province, PRC

4.1 Introduction

In this chapter, based on the results of the sample survey, we investigate the impact of small-scale CDM project on the reduction of GHGs. The site of this CDM project is Dingcheng village that is a suburb of Changde city in Hunan province in China, where stock breeding of pigs is one of the main industries. One of the main purposes of CDM is sustainable development of the host country or project area. This project also includes such two purposes as a reduction of GHG emissions and improvement of living standard of households in this village by early introduction of a scaled-down methane fermentation system using livestock excrement.

Introduction of this system, however, requires each household's own fund to some extent even if there is a subsidy from the local government. Therefore, it is rather difficult for low income households to introduce this system right now. Propping up this project by CDM scheme has a great possibility to make both environmental and financial contribution to the local society.

In the following part of this chapter, we will calculate the potentiality of GHG reduction and socio-economic effects given by introduction of small-scale methane fermentation system to pig breeders. In order to estimate socio-economic effects, a small-sample survey was conducted in December 2005. The survey results are summarized in the Table 4-1. In this area, usually every household breeds pigs indoor. Some pig breeding households introduce an efficient livestock waste management system, while others not. The survey covers 40 households. More than twenty questions were asked to two types of households. They are small-scale biogas plant introduced households and non-introduced ones. Hereafter we call them "introduced household" and "non-introduced household".

In order to give a clear image of CDM project there, it is better to sketch environmental surroundings in Dingcheng village and outline the present livestock waste management system. A large portion of households in this village breed two to five pigs indoor and keeps the excrement of the pigs in an open lagoon adjacent to the pig barn. Therefore, the present system not only emits methane that has a strong warming effect into air but also has an environmental risk on the local environments

(Figure 4-2 and Figure 4-3). On the other hand, environmental load that the households already introduced the methane fermentation system is relatively low. They can properly manage livestock excrement so that they can hinder methane gas from emitting into the air. Moreover, their living standard is also high since they can make use of methane gas as a substitutable energy source for the conventional ones such as cooking, heating and lighting. (Figure 4-4 and Figure 4-5)

Following the introduction, in section 2, we will show a brief summary of the survey results. Then, the socio-economic aspect of the small-scale CDM project will be considered in section 3. We estimated the yearly gains from the project such as energy, fertilizer and time savings in value terms when small-scale biogas plants are hypothetically installed. If these gains are used for enhancing human capital by receiving higher education, farmers are expected to increase their incomes overtime. This is so-called dynamic effects. Also the technological aspect of the project will be reviewed. We shed light on the simplified cost benefit analysis on small-scale CDM in section 4 and that on large-scale CDM in section 5. Finally in the conclusion we will explain some implications both from socio-economic and technological points of view. Our research suggests an introduction of small-scale biogas plant in a relatively poor region will contribute to helping secure sustainable developments in China.

4.2 Summary of Household Survey

This section is to review the results of the observation by examining difference between 'non-introduced households' and 'introduced households'.

4-2-1 Income related information

The average yearly income for non-introduced households is 19,808RMB (cash 7,675RMB, in-kind 12,133RMB), while that for introduced households is 37,525 (cash 22,125RMB, in-kind 15,400RMB). The latter is much higher than the former where this income gap is statistically significant by significant level of 1%. As Figure 4-6 shows, income distribution for introduced households is shifted large to the right comparing with that for non-introduced households. The main reason for the total income gap is the gap in the cash income as it is, while the gap in in-kind income is small and statistically insignificant. That is also justifiable since farmland area (for both wet rice field and dry field) has no statistically significant difference between two groups[1]. On the other hand, breeding number of pigs has statistically significant difference between two groups. Non-introduced households breed 2.1 pigs on average, while introduced households breed averagely 20.0 pigs that are approximately ten times larger than those of non-introduced households. As the break down of the income (item 19) shows, the income difference from husbandry (mainly pig) corresponds to the difference in cash income.

4-2-2 Energy related information

Except biogas, this region has such three energy sources as briquette, firewood, and straw[2]. To say nothing of it, quantity of those energies that non-introduced households consume is larger than those for introduced household; seven times on briquette, ten times for firewood and introduced households scarcely use straw as energy[3].

In order to see the difference of energy consumption structure, comparison of ‘pre-introduction’ and ‘post-introduction’ on introduced households would be more suitable. As is shown item 7 and item 8 of introduced households, post-introduction consumption of briquette became less than 10% and that of firewood became less than 5%. This information suggests biogas utilization is friendly to regional environment at least because that reduces consumption of briquette and firewood.

The survey has information on opportunity cost of energy procurement. Non-introduced households sacrifice as much as 4 hours per month for energy procurement while introduced households do not have to spend any time for that. It is clear that biogas plant introduction will greatly reduce households’ opportunity cost of energy procurement.

4-2-3 Fertilizer related information

Recalling that the farmland area is almost same between non-introduced households and introduced households, it is natural that required quantity of fertilizer is also same. Consumption quantity of chemical fertilizer of non-introduced households is three times as much as that of introduced households. This is because introduced households can use fermentation sludge of biogas generation as liquid organic fertilizer. Within introduced households before/after comparison, post-introduction consumption of chemical fertilizer is also no more than one third of

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1 The farmland area of not-introduced households is rather larger.
2 Kerosene and LPG are scarcely used as energy source.
3 It seems that it is because straws are used as fodder for pigs.

pre-introduction consumption. Naturally, consumption of liquid organic fertilizer of introduced households is four times larger than that of non-introduced households.

Interestingly enough, all of introduced households answer that the crop increased thanks to liquid organic fertilizer. It gives us side information for the reason that in-kinds income of introduced households is a little higher than that of non-introduced households. It is understood that use of biogas lowers the environmental load in the meaning of decreasing the consumption of chemical fertilizer.

4-2-4 Installation cost of biogas plant

According to the survey, installation of biogas plant costs a little over 2,000RMB (2,163RMB for non-introduced households). Since the cash income of non- introduced households is 7,675RMB, this amount corresponds to approximately 28.2% of the cash income. Taking the subsidy of 800RMB into account, indeed this amount could be affordable, but anyway this must be a big expense.

The pig-raising farmers are affluent thanks to cash income from swine, so that they have economic room to set up a biogas plant. Moreover, since biogas is easy-to-handle energy comparing with briquette or firewood, living environment for the introduced households improves. In other words, sarcastically enough, the current biogas plant project is supposed to expand the difference among local households. However, it is as described that the expansion of the biogas plant project contributes to decreasing environmental load compared with the current situation. Therefore, it is thought that the subsidy policy (promotion policy) that makes it possible for a petty pig raising household to introduce a small biogas plant contributes to sustainable development in the region.

4.3 Socio-Economic Analysis on Small-Scale CDM Project

In the previous section, we summarized the survey results of farmers' households. Surveyed households are divided into two groups and we figured out the characteristics among them. In this section, based on the survey results, we estimated the expected benefits numerically when non-introduced household hypothetically decides an installation of biogas plant.

4-3-1 Benefits: energy, fertilizer and time savings

When farm household introduces livestock waste management system, a biogas plant, there are three channels from where benefits arise. They are (1) energy savings, (2) fertilizer savings, and (3) time savings.

(1) Energy savings

In comparison with item 7 (present energy consumption) and item 8 (energy consumption before biogas introduction), introduced households reduced briquette consumption from 1,219kg to 99kg, firewood consumption from 1,878 kg to 80kg, and straw consumption from 1,790kg to 100kg respectively.

If we apply these rates of decrease in energy consumption to non-introduced households, we can calculate the hypothetical amounts of energy savings. They can save briquette consumption by 645kg on annual basis, reducing from 702kg to 57kg. For firewood, they can reduce its consumption from 750kg to 32kg, saving by 718kg. They can also cut straw consumption by 2,932kg, from 3,106kg to 174kg. In value terms, they can save money by 258RMB for briquette, by 144RMB for firewood and by 293RMB for straw[4]. In total, they are expected to save 695RMB.

(2) Fertilizer savings

The second benefit is the saving for fertilizer consumption. Comparison of item 12 (present consumption of chemical fertilizer) and item 13 (consumption of chemical fertilizer before introduction) shows that annual consumption of chemical fertilizer at introduced farm households decreased from 1,323kg in the case of pre-introduction to 516kg in post-introduction case. They appear to substitute chemical fertilizer with liquid organic fertilizer. This is because a biogas plant introduced household now can use stable fermentation sludge of livestock waste as liquid organic fertilizer. Before introduction, they used livestock waste in an inefficient way.

Now, let us apply this rate of reduction in fertilizer to non-introduced households. We can calculate the hypothetical amounts of fertilizer savings when they introduce a biogas plant. As a result of calculation, chemical fertilizer consumption is cut by 950kg, from 1,558kg to 608kg. Since cost of chemical fertilizer is averaged at 0.9RMB per kg, 860RMB are saved in value terms (see, Table 4-2).

A quick glance at item 14 (present consumption of liquid fertilizer) and item 15 (consumption of liquid fertilizer before introduction), introduced households increased their consumption of liquid fertilizer from 10,640ℓ in the case of

[4] From hearing, we set briquette price 0.4RMB per kg, firewood price 0.2RMB per

pre-introduction to 38,125ℓ after introduction. The more liquid organic fertilizer they use, the more crops they reap. Thanks to stable use of liquid organic fertilizer, introduced farmers' households can reduce chemical fertilizer consumption considerably. This is also co-benefit of chemical fertilizer savings (see, Figure 4-7).

(3) Time savings for energy procurement and housekeeping

The third benefit is time savings for energy procurement and housekeeping. According to item 9 (hours for collecting energy), non-introduced farm households spend about 4 hours per month for energy procurement. Once a biogas plant is introduced, hours for collecting energy can be used in another way. Farmers can be paid 150RMB when they work additional 48 hours per year. Here, from the hearing, we assume daily wage in rural area as 25RMB.

Item 23 (change in housekeeping hours after introduction) tells us that introduced households can reduce about 1 hour (median) for housekeeping. In other words, they can save 30 hours per month or 360 hours per year. If we assume 8 hours work per day, extra 45 days are available for them. This means they can realize 1,125RMB income since we set daily wages of part-timers at 25RMB.

Summing up, an introduction of biogas plant can create additional income of 2,830RMB (=695+860+150+1,125) for the farmers. Since average yearly income for non-introduced households amounts nearly 20,000RMB, they can increase their incomes by 14%. This is the total hypothetical income gains when they introduce a biogas plant.

4-3-2 Change in household consumption pattern

In the previous section, we estimated income gains when hypothetically farm households introduce a biogas plant. Here, let us take a glance at changes in consumption pattern when their incomes increase.

Table 4-3 shows the comparison of consumption patterns between non-introduced and introduced households (see, item 20). Per month amounts of consumption are averaged at 663RMB for non-introduced households and 1,071RMB for introduced households. Consumption level between two types of households is statistically different by a significant level of 1%. Introduced households spent 408RMB more than non-introduced household. Let us see which items contribute to the overall increase. First, the largest contributor is an expense on education, up

kg and straw price 0.1RMB per kg respectively.

178RMB. Then, transportation and telecommunication (by 66RMB), clothing and footwear (by 47RMB), and foods (43RMB) follow. We can easily guess that income increase from an introduction of biogas plant is mainly allocated to an expense on education.

Turn our eyes to consumption share by items. Comparing non-introduced and introduced households, share of foods was down 17.3 points from 55.7% to 38.4%, while that of education increased from 16.2% to 26.7%, up 10.5 points. Here, we also recognize that income increase from pig breeding is allocated mainly to increase in spending on education.

4-3-3 Dynamic effects: education and life-time income gain

Income increase offers a good opportunity for farmers to let their children take higher education, contributing to enhancing human capital. That in turn increases their incomes over time.

From the information of hearing, in Hunan Province, receiving higher education at the university costs a yearly average of 10,750RMB per person. Among the costs, 750RMB is needed for rent with range of 400RMB and 1,100RMB, 500RMB for education material such as books, 5,000RMB for living expense and 4,500RMB for tuition ranging from 3,400RMB to 5,700RMB. For the farmers' households with yearly income of 20,000RMB, it is quite a burden. However, it should be noted that living expenses for the university students vary in wide range depending on their economic conditions. According to the hearing results, the minimum expense is 2,000RMB and the maximum is 40,000RMB. If we assume minimum living expense, annual average cost for university students is estimated at 7,750RMB. The expected income increase arising from an introduction of biogas plant is 2,830RMB and this additional income will partly (by 14%) contribute to receiving university education.

There are far more merits than annual income increase. If successfully parents can give their children an opportunity for higher education, huge income gaps in life time will arise in comparison with the other case (high school education only). In order to recognize this, we calculate life-time incomes for them in the following way.

$$\text{Life-time income of high school grads} = \sum_{t=1}^{42} w_h \left(\frac{1+g}{1+r}\right)^{t-1} \quad (4\text{-}1)$$

$$\text{Life-time income of university grads} = \sum_{t=5}^{42} w_u \left(\frac{1+g}{1+r}\right)^{t-1} - C \quad (4\text{-}2)$$

Where w_h : initial wages of high school grads, w_u : initial wages of university grads, C: expense for university education (four years), g: rate of wage increase, r: discount rate.

According to the recent hearing, average monthly cash earnings are about 900RMB for high school grads, while monthly cash earnings for university grads are averaged at 1,750RMB with some range (see, Table 4-4). If high school grads work until 60 years old, their present value of life-time incomes is about 860,000RMB. Here, we assumed the rate of wage increase as 7% and the discount rate as 5%. On the other hand, the net present value of life-time incomes subtracting 4 year education cost for university grads amounts to about 1,170,000RMB when they work until 60 years old. The income gap of 310,000RMB arises from different education career (see, Figure 4-8). Taking this calculation into consideration, an introduction of biogas plant into rural area in the form of CDM project is recommendable as a policy choice and appears to improve the quality of life.

4-4 Cost-Benefit Analysis for a Small-Scale Livestock Waste Management System

This and the following sections are for a cost-benefit analysis of livestock waste management system that the CDM project assumes to introduce in Dingcheng village. Section 4-4 is for a small-scale livestock waste management system for a small pig breeder and Section 4-5 is for a relatively large system for a cow raising ranch.

4-4-1 Estimation of CH_4 emission reduction

Methane gas (CH_4) emission reduction by CDM is estimated as the difference between the baseline emissions and the project case emissions. It is assumed that the baseline methane emissions should be those from households using the conventional system for livestock excrement disposal. The equation (4-3) is the formula of CH_4 emissions from disposal of livestock waste of pig breeders without methane fermentation system.

$$\begin{aligned} E_{CH_4,without} &= VS \cdot B_0 \cdot D_{CH_4} \cdot MCF_1 \cdot GWP_{CH_4} \cdot 365/1000 \cdot N \\ &= 0.5 \cdot 0.45 \cdot 0.67 \cdot 0.9 \cdot 21 \cdot 365/1000 \cdot 2 = 2.0798 \end{aligned} \quad (4\text{-}3)$$

Where

$E_{CH4,without}$: CH_4 emissions from disposal of livestock waste (open air anaerobic lagoon) in tons of CO_2 equivalents per year.

VS: Volatile solid excretion per day on a dry-matter basis per livestock in kg-dm/head/day. For this calculation it will be considered the use of corrected default IPCC values.

B_0: Maximum CH_4 production capacity from manure per livestock population. (m^3 CH_4/kg-dm of *VS*).

D_{CH4}: CH_4 density (0.67kg/m^3 at room temperature, 20°C, and 1 atm pressure).

MCF_1: Methane Conversion Factor (MCF) for manure in the lagoon in percent.

GWP_{CH4}: Approved Global Warming Potential (GWP) of CH_4.

N: Livestock population of farmer house.

The value of *VS* is 0.5 kg/day/head that was taken from 'Volatile solid rate in raw manure of for developed countries' carried in tableB-2 of Appendix B Chapter4.2 in Revised 1996 IPCC Guidelines Reference Manual. This manual assumes that the standard pig weight is 82kg/head. Though the average pig weight in Dingcheng village is unknown, the same figure was used for the estimation. The value of B_0 was 0.45 m^3 CH_4/kg-dm of *VS* that was also taken from the same manual as *VS*. The value of MCF_1 is 90% that was taken from table4-8 temperate value for 'Anaerobic Lagoon' in the same manual since a pig breeder without methane fermentation system keeps the livestock excrement in an outdoor lagoon nearby. The value of GWP_{CH4} of methane is 21 as shown in Table 4-5.

On the CDM case, the volume of methane emissions from a household with the small-size methane fermentation system is calculated following the equation (4-4).

$$\begin{aligned} E_{CH4,with} &= VS \cdot B_0 \cdot D_{CH4} \cdot MCF_2 \cdot GWP_{CH4} \cdot 365/1000 \cdot N \\ &= 0.5 \cdot 0.45 \cdot 0.67 \cdot 0.15 \cdot 21 \cdot 365/1000 \cdot 2 = 0.3466 \end{aligned} \quad (4\text{-}4)$$

Where

$E_{CH4,with}$: CH_4 emissions from livestock waste management system in tons of CO_2 equivalents per year.

MCF_2: Methane Conversion Factor (MCF) for livestock waste management system in percent.

As to *VS*, B_0, DCH_4, and GWP_{CH4}, the values of those variables are same as those used in the equation (4-3) for the baseline case. As the system of this project is a scaled-down methane fermentation system, the value of MCF_2 could be the one carried in table4-10 'Liquid/Slurry system' in *IPCC Good Practice Guidance and Uncertainty Management*. We have no monitoring data for MCF, evaporation from liquid manure made of fermented excrement is out of our estimation, and there is some leakage from the digester tank. So the value of MCF_2 was assumed to be 15% that is the temperate value in the table 4-8 'Anaerobic Lagoon' in *Revised 1996 IPCC*

Guidelines Reference Manual.

4-4-2 Estimation of N_2O emission reduction

As for nitrous oxide emissions, the base line emissions and CDM case emissions are respectively calculated on the equation (4-5) and (4-6).

$$E_{N2O,without} = GWP_{N2O} \cdot NEX \cdot EF_{N2O1} \cdot CF / 1000 \cdot N$$
$$= 310 \cdot 16 \cdot 0.001 \cdot (44/28)/1000 \cdot 2 = 0.0155 \quad (4\text{-}5)$$

$$E_{N2O,with} = GWP_{N2O} \cdot NEX \cdot EF_{N2O2} \cdot CF / 1000 \cdot N$$
$$= 310 \cdot 16 \cdot 0.001 \cdot (44/28)/1000 \cdot 2 = 0.0155 \quad (4\text{-}6)$$

Where

$E_{N2O,without}$: Nitrous oxide emissions from disposal of livestock waste in tons of CO_2 equivalents per year.

$E_{N2O,with}$: Nitrous oxide emissions from livestock waste management system in tons of CO_2 equivalents per year.

GWP_{N2O}: Approved Global Warming Potential for N_2O.

NEX: Annual average nitrogen excretion per livestock in kg N/head/year.

EF_{N2O1}: N_2O emission factor for disposal of livestock waste in kg N_2O-N/kg N.

EF_{N2O2}: N_2O emission factor for livestock waste management system in kg N_2O-N/kg N.

CF: Conversion factor N_2O-N to N (44/28).

N: livestock population of farmer house.

The value of GWP_{N2O} for nitrous oxide is 310 as shown in Table 4-5. The value for NEX is 16kg N/head/year taken from table 4-20 ‘Asia & far East region’ carried in *Revised 1996 IPCC Guidelines Reference Manual*. The values of EF_{N2O1} and EF_{N2O2} are the same 0.001 that were taken respectively from table4-12 ‘Anaerobic Lagoon’ and ‘Anaerobic digester’. Since the emission factors for both cases are identical like this, the volume of N_2O emissions resulted in the same at least within the project boundary.

4-4-3 Estimation of total GHG emission reduction

Table 4-6 shows the GHG emission reductions per one farmer breeding two pigs by one year early introduction of small-scale methane fermentation system. The total reduction can be calculated by multiplying the number of pig breeders on which this CDM project targets.

From the table, methane gas is estimated to be cut down by 1.7 tons of CO2 equivalent in this unit case of the project. As mentioned above, there is no difference in the volume of N_2O emissions between baseline and project. So, total emission reductions in this case are calculated as 1.7 tons of CO2 equivalent.

Based on the result, we conducted a simplified cost-benefit analysis from the socio-economic views. The results are listed in Table 4-7. In the table, we prepared three cases depending on the difference of revenue coverage, while cost is common to all cases. This small-scale livestock waste management system costs 2,300RMB, while subsidy of 800RMB comes from local government. Thus the net cost for installation is 1,500RMB. On the other hand, service life of this system is assumed to be 20years. Annual running cost is 75RMB. For revenue calculation here, we assume one CER as a modest price of US$10 per ton of CO2. Total revenue is estimated to be 140RMB (=1.73*25/0.124) per year. In the basic case of the table, total revenue is 140RMB when only carbon credit is considered. As result, net revenue amounts to 65RMB per year. In the second case where additionally reduction of fuel consumption and chemical fertilizer are taken into revenue, net revenue amounts to 1,620RMB. In the third case where reduction in housekeeping and energy procurement are assumed as extra revenue, net revenue amounts to 2,895RMB.

4-5 Cost-Benefit Analysis for a Large-Scale Livestock Waste Management System

4-5-1 Background

As for a large-scale CDM project such as improvement in livestock excrement management system in a cow raising ranch with 1000 milk cows in Changde suburb and free flaring of evaporated methane as a reference case (see, Figure 4-9 and Figure 4-10), we estimate reduction of GHG emissions as well as initial cost of equipment and running cost for operation.

Let us start with the case of the cow raising ranch. This cow raising ranch first separates cows' excreta into solid part and liquid portion. And then the solid part is soled to local fisheries and the liquid portion is accumulated in an open air anaerobic lagoon. The accumulated liquid excreta is sometimes scattered to the surrounding farmland as liquid manure. According to the interview with the owner, he wants to introduce a methane fermentation plant in order to reduce environmental impacts, but he presently finds it difficult to do so without financial support. Therefore, we here consider the project that generates electricity using captured methane gas from fermentation of liquid excreta. We estimate benefits from selling extra electricity as well as reduction of GHG emissions.

4-5-2 Base Line of the Project

The baseline methane emissions are those from the present livestock waste management system (open air anaerobic lagoon). The equation (4-7) is the formula for that.

$$E_{CH4,1} = VS \cdot B_0 \cdot D_{CH4} \cdot MCF_b \cdot GWP_{CH4} \cdot 365/1000 \cdot N_y$$
$$= 2.82 \cdot 0.13 \cdot 0.67 \cdot 0.9 \cdot 21 \cdot 365/1000 \cdot 750 = 1270.8 \qquad (4\text{-}7)$$

Where

$E_{CH4,1}$: CH_4 emissions from livestock waste management system (open air anaerobic lagoon) in tons of CO_2 equivalents per year.

VS: Volatile solid excretion per day on a dry-matter basis per livestock in kg-dm/head/day. For this calculation it will be considered the use of corrected default IPCC values.

B_0: Maximum CH4 production capacity from manure per animal for a defined livestock population (m^3 CH_4/kg-dm of VS).

D_{CH4}: CH4 density (0.67kg/m^3 at room temperature, 20°C and 1 atm pressure).

MCF_b: Methane Conversion Factor (MCF) for treatment of livestock waste in the open air anaerobic lagoon in percent.

GWP_{CH4}: Approved Global Warming Potential (GWP) of CH_4.

N_y: Livestock of a defined population for year y.

The value of *VS* is 2.82 that was taken from tableB-1 ‘Asia, Dairy cattle’ of Appendix B Chapter4.2 carried in *Revised 1996 IPCC Guidelines Reference Manual*. The standard weight of caws of this value is 350kg/head. Though we have no information on the weight of dairy cows in this ranch, we assumed that the average weight in this ranch is also as heavy as the standard weight. The value of B_0 is 0.13 m^3 CH_4/kg-dm of *VS* that was also taken from the same manual. The value of MCF_1 is 90% that is taken from the temperate value in table 4-8 ‘Anaerobic Lagoon’ carried in the same manual. The value of GWP_{CH4} is 21 as shown in Table 4-5.

The baseline nitrous oxide emissions are those from the present livestock waste management system (open air anaerobic lagoon). The equation (4-8) is the formula for that.

$$E_{N2O\,1} = GWP_{N20} \cdot NEX \cdot EF_{N2O\,1} \cdot CF\ /\ 1000 \cdot N_y$$
$$= 310 \cdot 60 \cdot 0.001 \cdot (44/28)/1000 \cdot 750 = 21.92 \qquad (4\text{-}8)$$

Where

$E_{N2O\ 1}$: Nitrous oxide emissions from livestock waste management system (open air anaerobic lagoon) in tons of CO_2 equivalents per year.

GWP_{N20}: Approved Global Warming Potential for N_2O.

NEX: Annual average nitrogen excretion per livestock in kg N/head/year.

N_y: livestock of a defined population for year y.

$EF_{N2O\ 1}$: N_2O emission factor for treatment of livestock waste in the open air anaerobic lagoon in kg N_2O-N/kg N.

CF: Conversion factor N2O-N to N (44/28).

The value of GWP_{N20} is 310 as shown in Table 4-5. The value of *NEX* is 60kg N/head/year in table 4-20 'Asia & far East' carried in *Revised 1996 IPCC Guidelines Reference Manual*. The value of EF_{N2O1} is 0.001 in table4-12 'Anaerobic Lagoon' carried in *IPCC Good Practice Guidance*.

4-5-3 Project Activity

Methane emissions with CDM project can be divided into two parts. The first part is emissions from methane fermentation and the second part is those from storage lagoon of fermentation effluent. However, the methane fermentation for this project uses a sealing type of fermentation digester. So, taking it into consideration, methane emissions with CDM were estimated. The equation (4-9) and (4-10) are respectively the formula for the first part and the second part.

$$\begin{aligned} E_{CH4,\,2} &= VS \cdot B_0 \cdot D_{CH4} \cdot MCF_2 \cdot GWP_{CH4} \cdot 365/1000 \cdot N_y \\ &= 2.82 \cdot 0.13 \cdot 0.67 \cdot 0.0 \cdot 21 \cdot 365/1000 \cdot 750 = 0.0 \end{aligned} \tag{4-9}$$

$$\begin{aligned} E_{CH4,\,3} &= VS \cdot (1 - R_{VS}) \cdot B_0 \cdot D_{CH4} \cdot MCF_3 \cdot GWP_{CH4} \cdot 365/1000 \cdot N_y \\ &= 2.82 \cdot (1 - 0.85) \cdot 0.13 \cdot 0.67 \cdot 0.9 \cdot 21 \cdot 365/1000 \cdot 750 = 190.6 \end{aligned} \tag{4-10}$$

Where

$E_{CH4,\ 2}$: CH_4 emissions from livestock waste management (anaerobic digester) in first part of livestock waste management system in tons of CO_2 equivalents per year.

MCF_2: Methane Conversion Factor (MCF) for livestock waste management (anaerobic digester) in first part in percent.

$E_{CH4,\ 3}$: CH_4 emissions from livestock waste management (storage lagoon) in second part of livestock waste management system in tons of CO_2 equivalents per year.

R_{vs}: Relative reduction of volatile solids in the first part in percent.

MCF_3: Methane Conversion Factor (MCF) for livestock waste management (storage lagoon) in second part in percent.

The value of MCF_2 is 0 that was taken from table4-10 'anaerobic digester' carried in IPCC Good Practice Guidance and Uncertainty Management. In other words, it is assumed that there is no leakage of methane from the digester in this part. The value of R_{vs} is assumed to be 85% of *VS* that was taken from USEPA (2001) *Development Document for the Proposed Revisions to the National Pollutant Discharge Elimination system Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations* since *VS* is already digested in the first part. The value of MCF_3 is 90% that was taken from the temperate value in table4-8 'Anaerobic Lagoon' carried in *Revised 1996 IPCC Guidelines Reference Manual*.

As to nitrous oxide emissions, they are scarcely generated. We targeted only the emissions from the storage lagoon after the methane fermentation.

$$E_{N2O\,2} = GWP_{N20} \cdot NEX \cdot EF_{N2O\,1} \cdot CF\ /\ 1000 \cdot N_y$$
$$= 310 \cdot 60 \cdot 0.001 \cdot (44/28)/1000 \cdot 750 = 21.92 \quad (4\text{-}11)$$

Where

$E_{N2O\,2}$: Nitrous oxide emissions from livestock waste management system in tons of CO_2equivalents per year.

GWP_{N20}: Approved Global Warming Potential for N_2O.

NEX: Annual average nitrogen excretion per livestock in kg N/head/year.

N_y: Livestock of a defined population for year y.

$EF_{N2O\,2}$: N_2O emission factor for the second step of livestock waste management system in kg N_2O-N/kg N.

CF: Conversion factor N_2O-N to N (44/28).

The value of *GWP* for nitrous oxide is 310 as shown in Table 4-5. The value for *NEX* is 60kg N/head/year was taken from table 4-20 'Asia & far East region' carried in *Revised 1996 IPCC Guidelines Reference Manual*. The values of EF_{N2O1} and EF_{N2O1} are the same 0.001 that were taken respectively table4-12 'Anaerobic Lagoon' and 'Anaerobic digester'.

Power generation using captured methane will have two economic effects; the one is substituting effect of currently consuming electricity and the other is substituting effect of grid electricity by selling extra electricity. This project makes use of methane fermentation system using subcritical water and a power generator. The capacity of the generator is 1200kWh/day, where self consumption in the ranch is 100kwh/day and the extra electricity is 1,100kWh/day.

The substitution effect was estimated based on the equation (4-12). CO_2 emission factor of average grid electricity was taken from Clean Development Mechanism Project Design Document Form for "Nanjing Tianjingwa Landfill Gas to Electricity Project (2004)".

$$\begin{aligned} ER &= SE \cdot 365/1000 \cdot EF \\ &= 1100 \cdot 365/1000 \cdot 0.874 = 350.91 \end{aligned} \tag{4-12}$$

Where

ER: CO_2 emission reduction from displaced grid electricity in tons of CO_2 per year.

SE: Surplus electricity by project activity in kwh/day.

EF: CO_2 emission factor of average grid electricity in Mwh/year (0.874t-CO_2/MWh).

Total CO_2 emission reduction by Project Activity is estimated 1396.7 ton-CO_2/year based on the equation (4-13).

$$\begin{aligned} ER_{total} &= E_{base} - E_{pro} + ER \\ &= 1292.74 - 212.54 + 350.91 = 1431.11 \end{aligned} \tag{4-13}$$

Where

ER_{total}: Total CO_2 emission reduction by project activity.

E_{base}: CO_2 emission by baseline.

E_{pro}: CO_2 emission by project activity.

ER: CO_2 emission reduction by project activity.

The substitution effect was estimated based on the equation (4-12). CO_2 emission factor of average grid electricity was taken from Clean Development Mechanism Project Design Document Form for "Nanjing Tianjingwa Landfill Gas to Electricity Project (2004)".

In Table 4-8 and Table 4-9, estimated baseline emissions and project activity emissions are summarized. Total emissions are estimated to be 1292.7 tons of CO2 equivalent per year for the baseline, while those for project activity are estimated to be 212.5 tons. Also, emission reductions from displaced grid electricity amount to 350.9 tons. Thus, net reductions are estimated to be 1431.1 tons. Based on the estimates, we conducted cost-benefit analysis of large-scale CDM project in a simplified manner. The results are shown in Table 4-10. Main revenues consist of carbon credit and electric power selling, while costs are composed of operating costs, labor cost and initial investment. We prepare three cases with variation of CER prices ranging from US$5 to US$25. If we assume CER as US$5 or US$10, this project does not pay. But interestingly this project does pay in case of US$25.

Break-even price is US$22.

4.6 Implication from the Case Study

In the section 4-3, we focused on the socio-economic effects of introduction of small biogas plant. When farm household introduces livestock waste management system, there are three channels from where benefits arise. They are energy, fertilizer, and time savings. In total, farmers' households are expected to save 2,830RMB per year. Since average yearly income for non-introduced households amounts nearly 20,000RMB, they can increase their incomes by 14%. This is the hypothetical income gains when they introduce a biogas plant.

There are far more merits than income increase. Income increase offers a good opportunity for farmers to let their children take higher education, contributing to enhancing human capital. That in turn increases their incomes over time.

In section 4-4, we assessed the improvement in living standard of farmers' households by early introduction of a scaled-down methane fermentation system using livestock excrement. In section 4-5, a large-scale CDM project such as improvement in livestock excrement management system in a cow raising ranch with 1000 milk cows are considered.

Total emission reductions are estimated to be 1.7 tons of CO2 equivalent in this unit case of the small-scale project. For the large-scale CDM, net emission reductions are estimated to be 1431.1 tons. Based on the result, we conducted a simplified cost-benefit analysis of both small-scale and large-scale livestock waste management system. When we assume CER price as a modest US$10 per ton of CO2, net revenue amounts to 65RMB per year in the case of small-scale CDM. If additionally reduction of fuel consumption, chemical fertilizer and housekeeping hours are taken into revenue, net revenue will increase further more. On the other hand, in case of the large-scale CDM project, if we assume CER as US$5 or US$10, this project does not pay. But interestingly this project does pay in case of US$25. Break-even price is US$2.

We can say an introduction of biogas plant into rural area in the form of CDM project will contribute to helping secure sustainable developments in China.

Figure 4-1 Position of Hunan Province in China

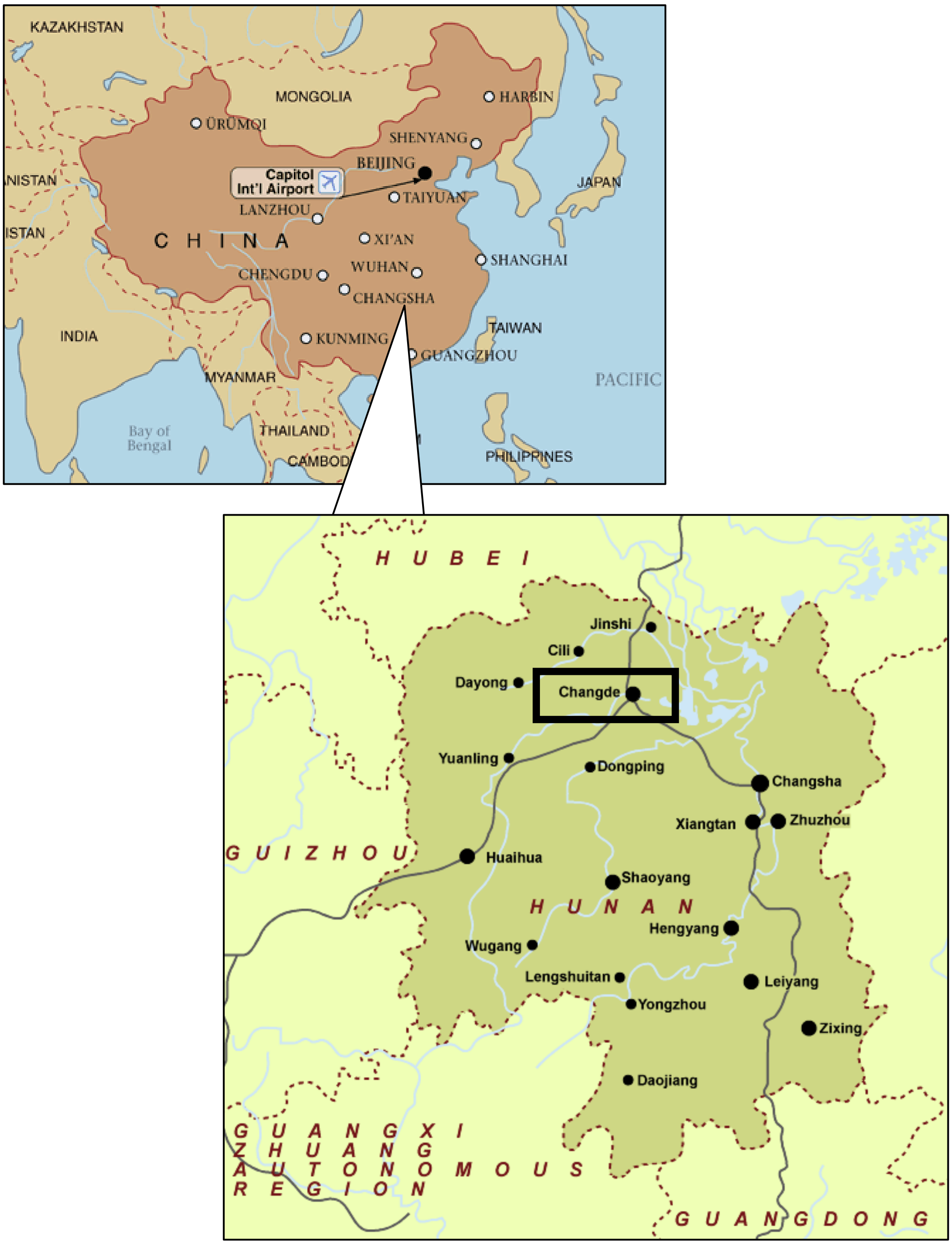


Table 4-1 Summary of household survey in Dingcheng, Changde City, Hunan Province, PRC

Category 1	Category 2	Unit	Non introduced households					Introduced households				
			Sample size	Mean	Standard Deviation	Maximum	Minimum	Sample size	Mean	Standard Deviation	Maximum	Minimum
1 Number of family member		person	20	3.8	1.1	6	2	20	4.1	0.9	6	3
2 Yearly income	Total	RMB	20	19,808	7,489	43,000	9,000	20	37,525	18,175	78,400	22,000
	Cash	RMB	20	7,675	5,858	18,000	200	20	22,125	13,917	60,000	2,000
	in kind	RMB	20	12,133	7,268	33,000	3,000	20	15,400	16,867	70,200	1,700
3 Filed area	Total	m^2	20	6,935	3,104	13,200	1,200	20	6,776	3,440	15,160	1,980
	Rice filed	m^2	20	6,575	2,862	13,200	1,200	20	6,188	3,375	13,200	1,980
	Non rice field	m^2	20	360	701	3,200	0	18	654	1,042	4,010	0
4 Number of livestock	Total	head	20	33.8	6.9	43	20	20	64.1	42.0	137	7
	Pig	head	20	2.1	0.8	3	1	20	15.6	16.2	58	3
	Boar	head	20	0.0	0.0	0	0	19	0.1	0.3	1	0
	Breeding pig	head	20	0.3	0.6	2	0	20	2.9	6.3	28	0
	Meat pig	head	20	1.6	0.9	3	0	20	12.6	13.4	53	0
	Cow	head	20	0.4	0.7	2	0	19	0.2	0.7	3	0
	Meat cow	head	20	0.4	0.7	2	0	20	0.2	0.7	3	0
	Milk cow	head	20	0.0	0.0	0	0	20	0.0	0.0	0	0
	Sheep	head	20	0.0	0.0	0	0	20	18.1	34.3	108	0
	Fowl	head	20	31.3	6.6	40	18	20	30.3	19.7	80	0
5 Excreta volume from livestock	Pig	kg/day	20	21.0	0.0	21	21	20	21.0	0.0	21	21
	Meat cow	kg/day	20	54.0	0.0	54	54	20	54.0	0.0	54	54
	Milk cow	kg/day	20	58.0	0.0	58	58	20	58.0	0.0	58	58
	Sheep	kg/day	20	3.5	0.0	4	4	20	3.5	0.0	4	4
	Fowl	kg/day	20	0.2	0.4	2	0	20	0.1	0.0	0	0
6 Biogas consumption		m^2/day						20	13.6	47.7	216.0	2.2
Share(%)	Cooking	%						20	38.5	9.9	60.0	10.0
	Hot water supply	%						20	18.5	3.7	20.0	10.0
	Lighting	%						20	14.0	6.0	20.0	0.0
	Others	%						20	27.0	10.3	50.0	10.0
7 Present energy consumption	Briquette	kg/year	20	701.5	337.5	1,800	300	20	99.0	61.1	200	0
	Firewood	kg/year	20	749.5	292.9	1,200	300	19	80.0	112.7	400	0
	Straw	kg/year	20	3,106.0	3,756.0	15,000	120	17	100.0	264.6	1,000	0
	Coal	kg/year	20	0.0	0.0	0	0	18	0.0	0.0	0	0
	Oil	ℓ/year	20	0.0	0.0	0	0	18	0.0	0.0	0	0
	LPG	m^3/year	20	4.2	8.9	24	0	18	0.0	0.0	0	0

Table 4-1 Summary of household survey in Dingcheng, Changde City, Hunan Province, PRC (continued)

Category 1	Category 2	Unit	Non introduced households					Introduced households				
			Sample size	Mean	Standard Deviation	Maximum	Minimum	Sample size	Mean	Standard Deviation	Maximum	Minimum
8 Energy consumption before biogas introduction	Briquette	kg/year						20	1,219.0	565.4	2,000	0
	Firewood	kg/year						20	1,878.0	1,751.9	6,000	360
	Straw	kg/year						20	1,790.0	1,280.6	5,000	0
	Coal	kg/year						20	0.0	0.0	0	0
	Oil	ℓ/year						20	0.0	0.0	0	0
	LPG	m^3/year						20	9.6	18.5	60	0
9 Hours for collecting energy		hour/month	20	4.0	0.2	4	3	8	0.0	0.0	0	0
10 Hours for collecting energy before introduction		hour/month						20	4.1	0.3	5	4
11 Present consumption of chemical fertilizer		RMB						20	467.0	230.0	1,000	160
12 Present consumption of chemical fertilizer		kg/year	20	1,558	1,581	8,000	400	20	516.0	399.6	2,000	160
13 Consumption of chemical fertilizer before introduction		kg/year						20	1,322.5	806.3	4,000	400
14 Present consumption of liquid fertilizer		ℓ/year	20	8,595	3,522.6	20,000	2,500	20	38,125.0	21,452.4	100,000	4,500
15 Consumption of liquid fertilizer before introduction		ℓ/year						20	10,640.0	4,622.9	20,000	1,000
16 Increment of crop after introduction		kg/year						20	537.5	207.0	1,000	250
17 Finance for biogas plant		RMB	19	2,163.2	526.2	2,300	0	20	2,333.5	651.3	5,000	2,000
	Own Funds	RMB	20	1,335.0	459.1	1,500	0	20	1,508.5	670.1	4,200	800
	Subsidy	RMB	20	720.0	246.2	800	0	20	800.0	0.0	800	800
	Loan	RMB	20	0.0	0.0	0	0	17	29.4	121.3	500	0
18 Expected time to introduce biogas plant (years later)		year	20	1.7	0.6	2	0					
19 Net yearly income 1)		RMB	20	11,802.5	4,701.1	25,000	5,800	20	20,525.0	6,785.5	38,000	12,000
	Total	RMB	20	13,620.0	4,498.0	23,000	5,200	20	10,945.0	4,567.1	23,000	3,600
	Rice 2)	RMB	20	11,860.0	4,395.3	20,000	4,000	20	8,365.0	3,436.1	15,000	3,000
	Vegetables 2)	RMB	20	470.0	435.4	2,000	0	20	1,235.0	2,430.4	10,000	0
	Fruits 2)	RMB	20	375.0	673.5	3,000	0	19	842.1	1,828.3	8,000	0
	Flowers 2)	RMB	19	10.5	45.9	200	0	18	277.8	1,178.5	5,000	0
	Others 2)	RMB	19	952.6	712.9	2,000	0	20	325.0	344.7	1,000	0
	Animal husbandry	RMB	20	2,177.5	807.3	3,500	850	20	17,095.0	17,976.8	64,000	2,000
	Fishery	RMB	19	578.9	2,292.9	10,000	0	20	435.0	1,386.1	6,000	0
	Manufacturing	RMB	19	0.0	0.0	0	0	20	0.0	0.0	0	0
	Construction	RMB	19	184.2	691.4	3,000	0	20	745.0	1,271.3	3,500	0
	Commerce	RMB	19	126.3	378.4	1,200	0	18	2,222.2	8,941.3	38,000	0
	Others 3)	RMB	20	4,165.0	4,939.7	18,000	200	20	5,775.0	6,673.7	20,000	500
	Total	RMB	20	20,892.5	7,561.4	46,000	9,000	20	36,995.0	18,657.3	78,400	21,400

Table 4-1 Summary of household survey in Dingcheng, Changde City, Hunan Province, PRC (continued)

Category 1	Category 2	Unit	Non introduced households					Introduced households				
			Sample size	Mean	Standard Deviation	Maximum	Minimum	Sample size	Mean	Standard Deviation	Maximum	Minimum
20 Monthly consumption expenditure		RMB	20	663.0	262.6	1,250	315	20	1,071.2	451.6	2,280	500
	Food	RMB	20	369.0	103.2	600	200	20	411.5	125.9	700	250
	Rent	RMB	20	5.0	22.4	100	0	20	15.0	36.6	100	0
	Electricity	RMB	20	25.1	9.0	50	15	20	44.6	20.2	80	20
	Electricity (quantity)	kw	20	50.2	17.9	100	30	20	86.2	40.9	160	40
	Gas	RMB	20	0.0	0.0	0	0	20	0.0	0.0	0	0
	Gas (quantity)	m^3	20	0.0	0.0	0	0	20	0.0	0.0	0	0
	Water	RMB	20	0.0	0.0	0	0	20	5.1	5.3	13	0
	Household utensil	RMB	20	25.5	10.0	50	0	20	50.5	27.0	100	20
	Clothing & footware	RMB	20	51.0	40.2	200	20	20	98.0	71.3	300	30
	Health and medical care	RMB	20	27.5	18.6	100	10	20	46.2	30.8	100	20
	Transportation & communicatio	RMB	20	51.9	29.2	150	30	20	117.4	41.9	200	50
	Education	RMB	20	107.5	173.2	500	0	18	285.6	331.9	1,000	0
	Culture and entertainment	RMB	20	0.5	2.2	10	0	18	20.6	30.0	100	0
	Others	RMB	20	0.0	0.0	0	0	20	7.5	20.7	80	0
21 Monthly non consumption expenditure [4)]		RMB	17	5.3	7.2	20	0	18	24.2	37.1	100	0
22 Change in education period after introduction		year						5	0.0	0.0	0	0
23 Change in housekeeping hours after introduction		hour/day						18	1.6	0.9	4	1
Saved time is used for								4	0.0	0.0	0	0
	Farming	hour/day						18	1.3	1.1	4	0
	Other works	hour/day						12	1.0	1.3	3	0
24 Change in disease medical treatment days after introduction		day/year						6	10	0.0	10	10

1)Net income, or gross income - required cost

2)Gross income

3)Including works away from home and part time jobs

4)Tax, social security contribution, etc.

Figure4-2 Flowchart of livestock waste disposal system for a pig breeder without methane fermentation system

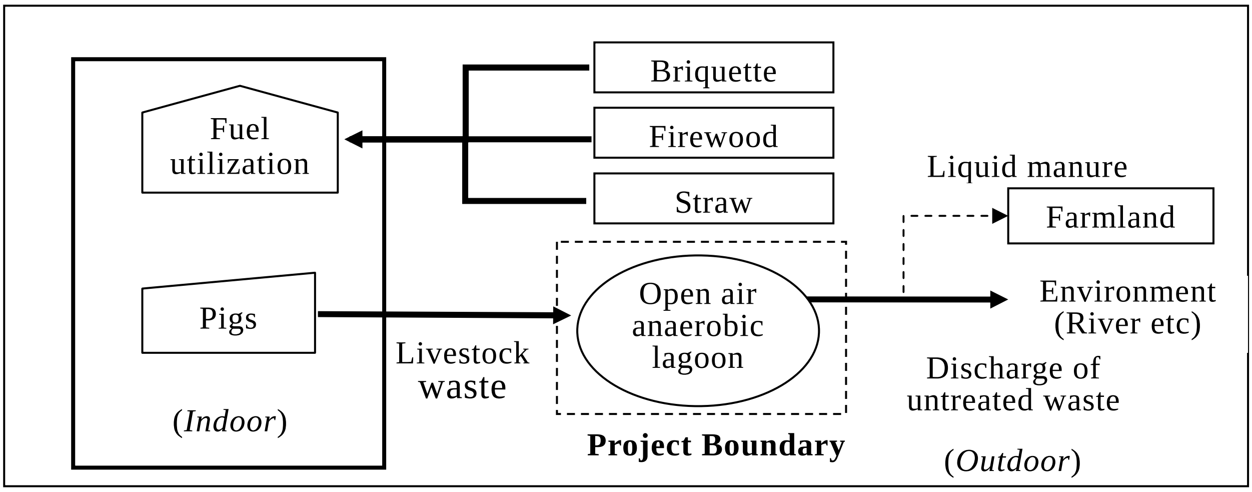


Figure4-3 Disposal of livestock waste of farmer house without methane fermentation system

Figure 4-4 Flowchart of livestock waste management for a pig breeder with methane fermentation system

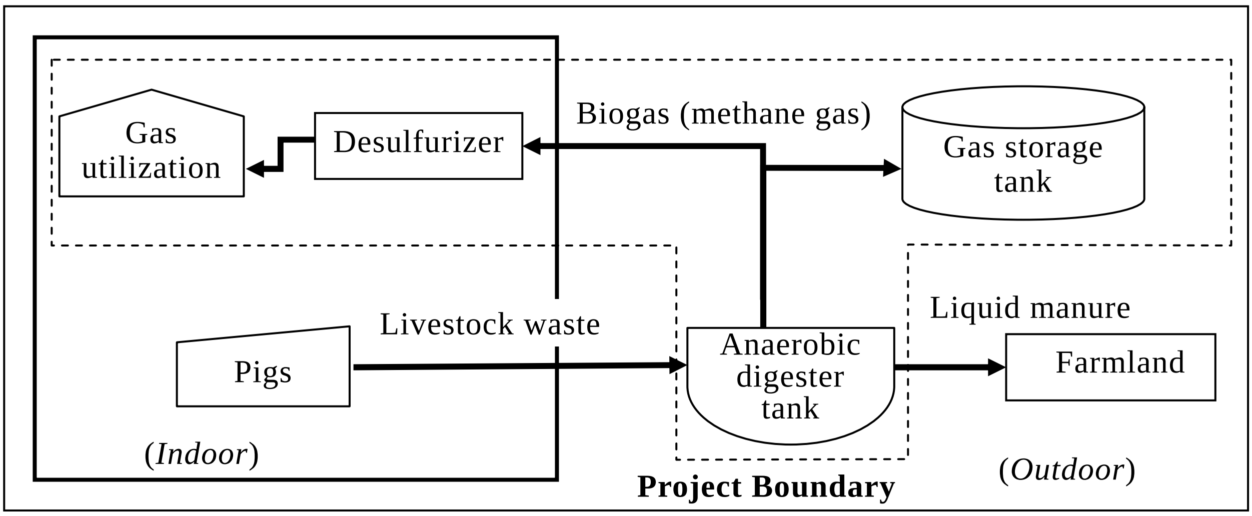


Figure 4-5a Prototype of scaled-down methane fermentation system

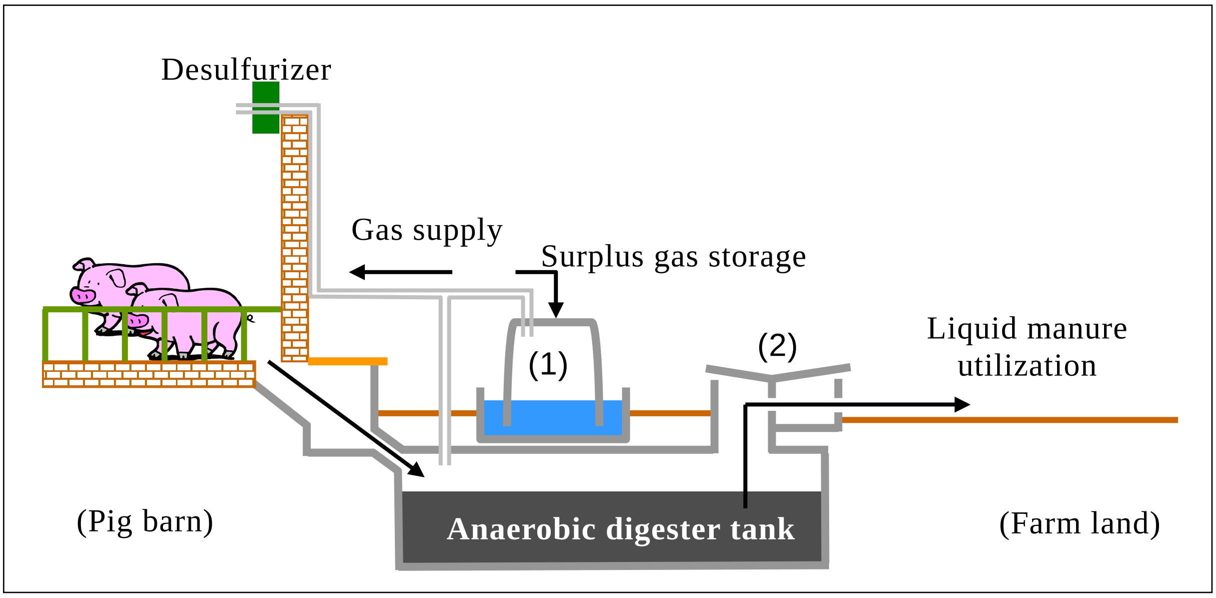


Figure 4-5b Pictures of scaled-down methane fermentation system


(1) in Figure 4-5a


(2) in Figure 4-5a

Figure 4-6 Distribution of yearly income in Dingcheng village (sample size =20)

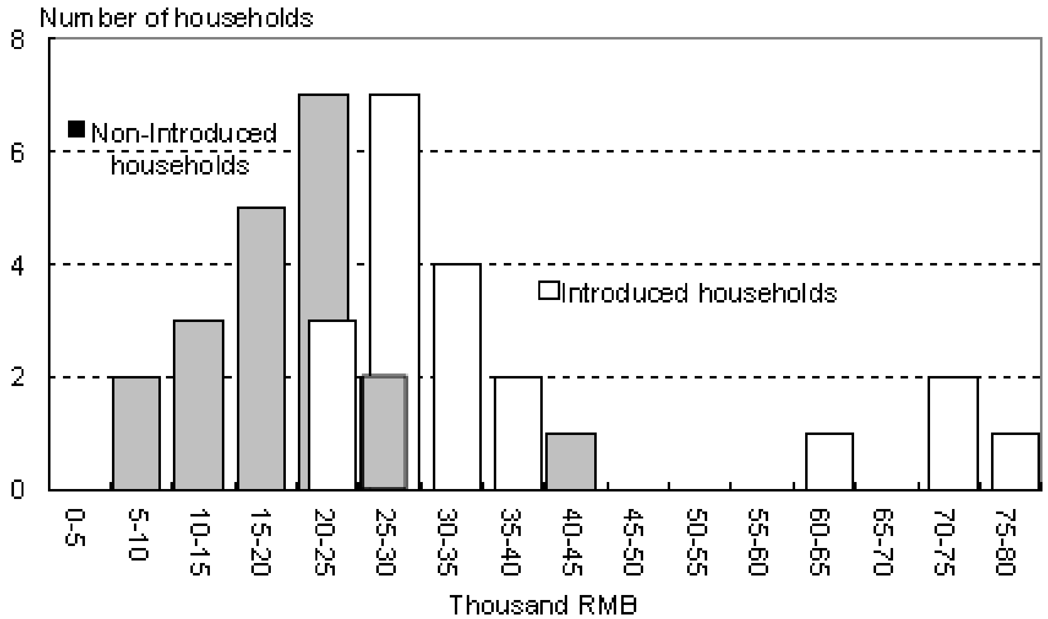


Table 4-2 Estimated amounts of energy and chemical fertilizer consumption

	Briquette	Firewood	Straw	Chemical Fertilizer
Consumption before introduction	702	750	3,106	1,558
Consumption after introduction	57	32	174	608
Difference	645	718	2,932	950
Saving (RMB)	258	144	293	860

Unit: kg (briquette, firewood and straw), ℓ (chemical fertilizer)

Figure 4-7: Crop increase and liquid organic fertilizer

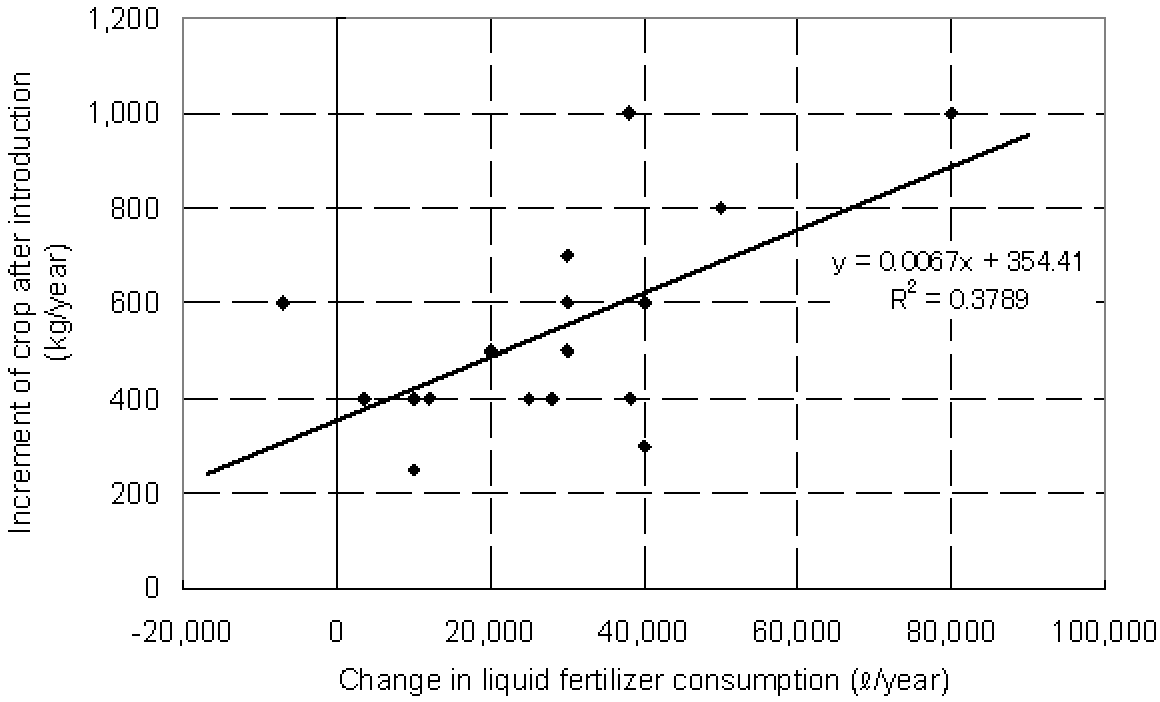


Table 4-3 Consumption patterns of non-introduced and introduced households

	Food	Rent	Electricity	Gas	Water	Household utensil	Clothing & footwear	Health & medical care	Transportation & communication	Education	Culture & entertainment	Others
Non-introduced	369.0	5.0	25.1	0.0	0.0	25.5	51.0	27.5	51.9	107.5	0.5	0.0
Composition	55.7%	0.8%	3.8%	0.0%	0.0%	3.8%	7.7%	4.1%	7.8%	16.2%	0.1%	0.0%
Introduced	411.5	15.0	44.6	0.0	5.1	50.5	98.0	46.2	117.4	285.6	20.6	7.5
Composition	38.4%	1.4%	4.2%	0.0%	0.5%	4.7%	9.1%	4.3%	11.0%	26.7%	1.9%	0.7%

Unit: RMB per month, %

Table 4-4 Assumption set for life time income calculation

	Initial Wage (RMB)	Wage increase rate	Discount rate	Expense for university education (RMB)
High school grads	900	7%	4%	-
University grads	1,750	7%	4%	43,200

Figure 4-8 Discount value of yearly income for university and high school grads

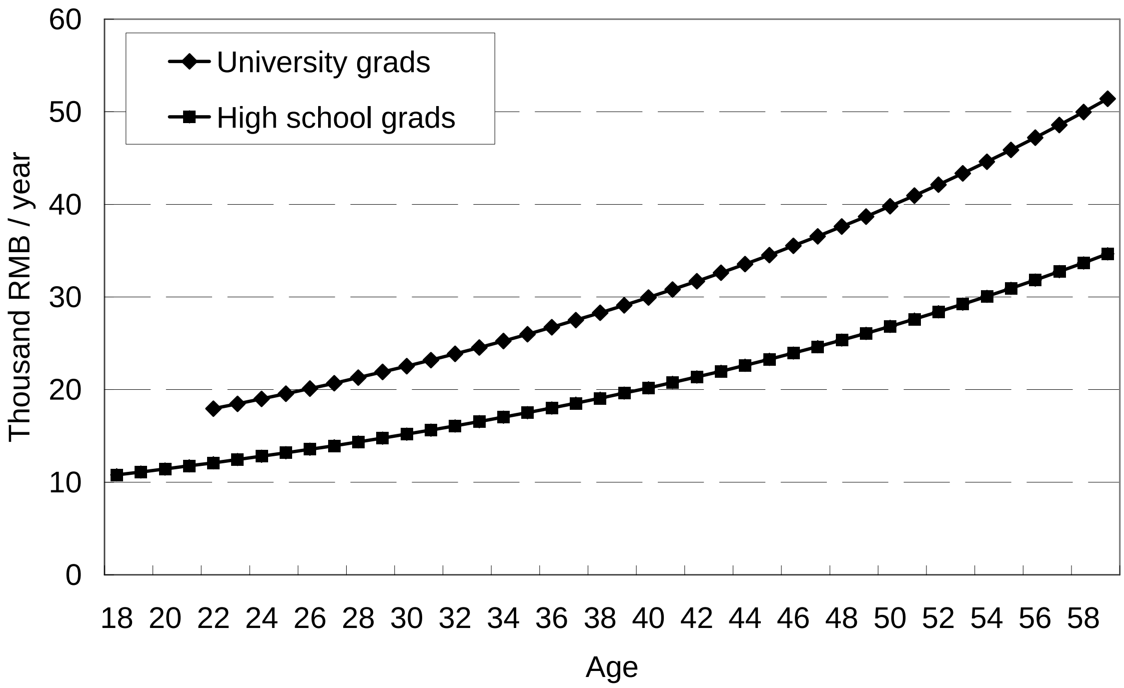


Table 4-5 Global warming potential

	Carbon dioxide	Methane	Nitrous oxide
Global warming potential	1	21	310

Table 4-6 GHG emission reductions by one year early introduction of small-scale methane fermentation system

Emissions (tCO2eq)/year	Baseline	Project	Emission reductions
CH4	2.08	0.35	1.73
N2O	0.016	0.016	0
Total	2.096	0.366	1.73

Table 4-7 Simplified cost-benefit analysis: Small-scale CDM Project

1) Basic case

	CER:10US$/ton-CO2
Revenue	
Carbon credit	140
Total	140
Running cost	
Operating cost	0
Labor cost	0
Initial cost(depreciation)	75
Total	75
Cash flow	65

Unit: RMB

2) Basic case + energy & fertilizer savings

	CER:10US$/ton-CO2
Revenue	
Carbon credit	140
Reduction of fuel consumption	695
Reduction of chemical fertilizer	860
Total	1695
Running cost	
Operating cost	0
Labor cost	0
Initial cost(depreciation)	75
Total	75
Cash flow	1620

Unit: RMB

3) Basic case + energy & fertilizer savings + time savings

	CER:10US$/ton-CO2
Revenue	
Carbon credit	140
Reduction of fuel consumption	695
Reduction of chemical fertilizer	860
Reduction of housekeeping & energy procurement	1275
Total	2970
Running cost	
Operating cost	0
Labor cost	0
Initial cost(depreciation)	75
Total	75
Cash flow	2895

Unit: RMB

Table 4-8 Detailed Baseline Emissions

Emissions (tCO2eq)/year	
CH4	1270.82
N2O	21.92
Total	1292.74

Table 4-9. Detailed Project Activity Emissions

Emissions (tCO2eq)/year	
Anaerobic digester (CH4)	-
Anaerobic digester (N2O)	-
Lagoon (CH4)	190.62
Lagoon (N2O)	21.92
Total	212.54

Table 4-10 Simplified Cost-Benefit analysis: Large-scale CDM Project

	CER:5US$ /ton-CO2	CER:10US $/ton-CO2	CER:25US $/ton-CO2	Note
Revenue				
Electric power selling	136,802	136,802	136,802	
Carbon credit	57,706	115,412	288,529	
Total	194,508	252,214	425,331	
Running cost				
Operating cost	66,917	66,917	66,917	
Labor cost	24,000	24,000	24,000	1000 (RMB/month) * 12 (month)
Total	90,917	90,917	90,917	
Depreciation				
Reactor equipment	71,665	71,665	71,665	Digester tank, subcritical water equipment
Attached equipment	17,916	17,916	17,916	Boiler, pump, cooling tower, and cooling pump, compressor
Electrical generating equipment	180,754	180,754	180,754	Gas engine
Others[1)]	23,291	23,291	23,291	
Total	293,627	293,627	293,627	
Cash Flow	-190,037	-132,331	40,787	

Unit: RMB

1) Others include construction costs and indirect costs.

Figure 4-9 Flowchart of livestock waste management system (baseline)

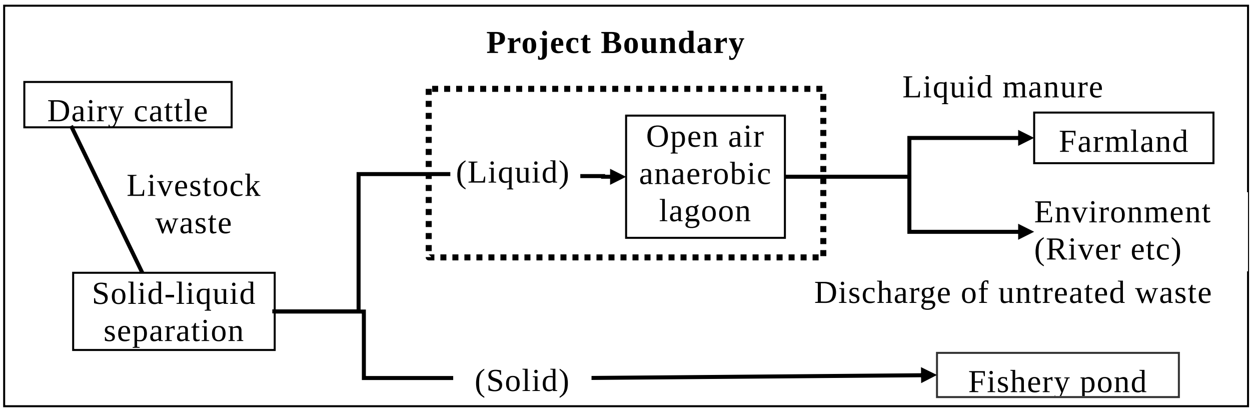
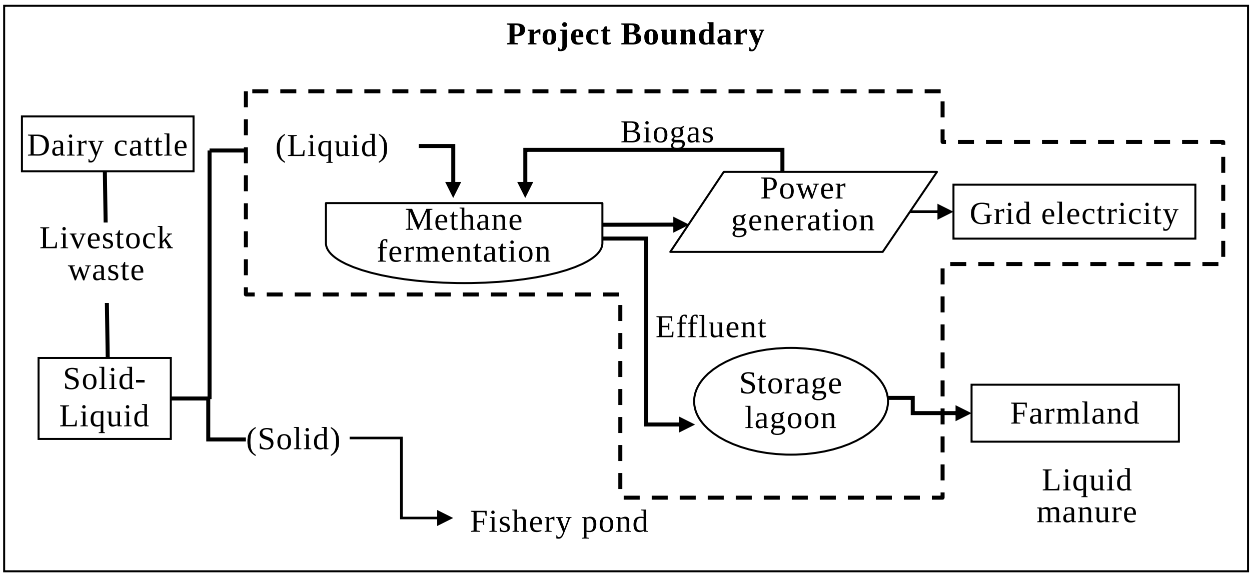


Figure 4-10 Flowchart of livestock waste management system (project activity)



Chapter 5 Concluding Remarks

The CDM allows Annex I countries to implement GHG emission reduction projects and receive credit in the form of certified emission reductions (CERs). The CDM also strives to promote sustainable development in developing countries. From the developing countries perspective, the benefits arise both from the increased investment flows and the requirement that these investments should advance their sustainable development goals, such as technological and financial transfer, local environmental benefits, poverty alleviation and equity consideration, and sustainable energy consumption. The twin purposes of the CDM require us to evaluate it in view of not only from investors who pursue higher rate of return from the projects, and from host countries who want to maximize its sustainable development impacts to their countries.

Conventional researches have strived to clarify the relationship between climate change policies and measures, and sustainable development both the theoretical analysis of sustainable development and ancillary benefit study of climate change policies. The former approach has emphasized the environmental, social, and economic dimensions, but yet offered any operational guidelines. The latter tends to focus exclusively on local pollution and health benefits to estimate the benefits, but has little attention to other environmental and socio-economic impacts. To evaluate the CDM comprehensively to compare different types of CDM projects, it is indispensable to take the concept of sustainable development impact s.

In this report, we strived to establish evaluation framework to compare different types of CDM projects by employing the concept of sustainable development impact. In Chapter 2, we reviewed how sustainable development objective of the CDM is to be advanced in theory, in host country criteria and at project level, and clarified the discrepancies among them. In Chapter 3 and 4, we conducted case studies of different types of CDM projects, taking sustainable development impacts into consideration. The main findings are as follows:

1) Theoretical arguments suggest that CDM projects that advance sustainable development both globally and locally should be implemented. However, it is highly unlikely for host countries to advance its sustainable development goals through the CDM because of high share of N_2O and HFC-23 reduction projects,

low share of small-scale projects, and host country's focus on economic dimension and technology transfer. China is relatively better, for it assess social and environmental dimension of sustainable development when choosing the CDM.

2) From a case study of CDM project of efficient power plant, we find that sustainable development impacts are so large that that social benefit becomes positive under some conditions, even if we limit the impact to health benefits. We can find, however, conflict of interests between project developers and host country in that the former will gain negative profit.
3) From a case study of CDM projects of livestock waste management system, we find this project is desirable for both project developers and local farmers for it brings net profit to the former and offers opportunity to enhance life-time income to the latter. On the other hand, we can find conflict of interests between project developers and host country in the large-scale waste management system CDM project

The above analysis may still be immature in that it does not include all the components of sustainable development impacts. Nonetheless, we can show that evaluation framework is effective in analyzing and comparing different types of CDM projects on the same ground when we include the concept of sustainable development impact. We can also show why potential CDM projects are not implemented even though they bring large socio-economic impacts.

However, it still remains to be a challenge to define sustainable development impacts in the CDM projects. In the UN Framework Convention on Climate Change, host countries can decide the definition of sustainable development when they publish criteria for the CDM. It may be the cases, however, that sustainability at the global level will not be ensured even if the project satisfies the host country's sustainable development criteria. In addition, host countries may abuse their sustainable development criteria to attract more CDM projects.

This challenge is originated from the fact that strict evaluation framework for sustainable development impacts has yet been established, due partly to the increasing complexity of the definition of sustainable development and its indicator. To enhance sustainable development impact at both global and local level, it is indispensable to establish such an evaluation framework