APN
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Scientific Capacity Building & Enhancement for Sustainable Development in Developing Countries

Capacity Building for Greenhouse Gases Inventory Development in Asia-Pacific Developing Countries

Final Report for APN 3-year CAPaBLE Project:
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2005-CB05CMY-Nakane

Final Report submitted to APN

Overview of project work and outcomes

Non-technical summary

Developing countries are particularly vulnerable to the adverse impacts and threats of climate change. To help prioritise countermeasures against those impacts and threats, greenhouse gas (GHG) inventories that can provide an accurate knowledge of GHG emission/removal trends are critically important. In Asia, it is known that the country-specific information for emission/removal factors and activity data, which are essential to prepare reliable GHG inventories, is not readily available. Moreover, although the degree of development of inventories varies widely, forums for neighbouring countries to share information and experiences related to GHG inventory development have not been established enough.

The ultimate goal of this project was to clarify the methodology for effectively improving inventories of countries in the Asia region and enhance the regional contribution to the relevant international efforts. Pilot studies were implemented in Cambodia and Thailand to demonstrate the comprehensive and source-specific approaches to improve inventories. The former identified the priority areas of inventories for improvement by primarily studying the entire aspects of them. The latter adopted measures to improve the inventories of particular source categories, given speciality available. In addition to implementing the pilot studies, the progress and outcomes of the studies were shared in annual regional workshops.

Objectives

The present project aimed to:

- carry out pilot studies on improvement of GHG inventories for effective countermeasures
- make sustainable systems to develop GHG inventories with well organised contribution from researchers and government officials
- provide more realistic emission factors reflecting country and regional conditions
- exchange information and experiences to establish accurate activity data
- clarify the direction to apply the methodologies developed in the plot studies to all Asia-Pacific countries
- enhance involvement and leadership of Asia-Pacific developing countries in the international efforts to improve GHG inventories and their application to mitigation against global warming
- provide policy makers with basic information to formulate and implement measures to reduce GHG emissions and enhance GHG removals

Amount received and number years supported

The Grant awarded to this project in three years was:

- US$ 39,500 for Year1, US$ 39,937 for Year2 & US$ 38,650 for Year3

Note: The regional workshops, titled as “The Workshop on GHG Inventories in Asia Region (WGIA)”, are sponsored by the Ministry of the Environment of Japan, except the participation of a project collaborator from Thailand in the 2nd workshop held in February 2005, in Shanghai, China, which was supported by the APN funds.

Work undertaken

The project is executed by the following institutes and organisation:

- National Institute for Environmental Studies (NIES) in Japan
- Ministry of Environment of Cambodia (MoEC)
- The King Mongkut’s University of Technology Thonburi (KMUTT) in Thailand

The project activities are divided into three: a pilot study in Cambodia, one in Thailand, and inputs to a regional workshop. Work undertaken in the three-year project duration, from April 2003 to March 2006, is summarised in the table below.

Year 1		
	Pilot study in Cambodia	The collaborator's meeting in March at NIES studied the feature of Cambodia's GHG inventories thoroughly and prepared a well-structured file system for Cambodia's inventories. It also identified the categories of the Land Use, Land-Use Change, and Forestry (LULUCF) sector as the key source/sink categories for Cambodia.
	Pilot study in Thailand	The training in March at NIES assembled the portable CH_4 and CO_2 semiconductor sensor, developed by NIES, from parts and confirmed its potential to effectively and reliably measure the concentration changes of CH_4 and CO_2 in the air by testing it.
	Inputs to regional workshop	In the First WGIA in November in Phuket, Thailand, the overview of the project was introduced and suggestions were made.
Year 2		
	Pilot study in Cambodia	Frequent e-mail-based discussion and literature review identified the methodology to improve the GHG inventories of the LULUCF sector in Cambodia, including the direct measurement of tree growth rate and aboveground biomass of forests. After the training in December in Cambodia, the first-time forest measurement was implemented in the plots established.
	Pilot study in Thailand	The training in August at NIES tested the sensor in the rice fields and reconstructed it due to the needs arose. Following the training in February at KMUTT, the measurement of the flux of CH_4 emissions from irrigated paddy fields under different fertilization modes were conducted with the sensor to estimate emission factors.
	Inputs to regional workshops	In the Second WGIA in February in Shanghai, China, the progress of the two pilot studies was reported.
Year 3		
	Pilot study in Cambodia	The meeting in October at MoEC created a series of spreadsheets to develop inventories for 2000 based on the measured and newly-estimated data. The second-time forest measurement was then conducted following the methodology developed. The new estimation of emissions and removals for 2000 and a full report including the explanation of the estimation procedure were prepared.
	Pilot study in Thailand	The training in October at KMUTT reconstructed the sensor to improve the measurement efficiency in rice paddies. It also examined the new methodology with the laser gas detector to measure CH_4 flux in landfills. The measurements in rice paddies, both in irrigated and rainfed rice fields, and landfills were carried out, followed by the analysis and reporting of the measurement results.
	Inputs to regional workshops	In the Third WGIA in February in Manila, the Philippines, the progress of the two pilot studies was reported.

Results

The project generated a number of outputs that are related to the original objectives of this project.

<Pilot study in Cambodia>
An inventory of the LULUCF sector for the year 2000 was prepared by applying the developed original emission/removal factors, based on forest measurement, and activity data to the well-structured file system. A full report on the methodology and procedure taken under the study, which could be included in the subsequent national communications of the country to the UNFCCC, was created. The standard forest measurement technique was learnt and the availability of local information and data was improved.

<Pilot study in Thailand>
The semiconductor sensor, which is more mobile and easier to use than the conventional measurement method, was constructed from parts by one of the project collaborators from Thailand and its ability to measure methane flux in rice fields was tested and confirmed. With this sensor, the emission factors for methane emissions from irrigated rice paddies under different treatments and rainfed rice paddies were developed and then compared with old factors. Together with this semiconductor sensor, the other measurement methodology using the laser gas detector was applied for the measurement of methane flux from landfill sites and the potential of the methodology for such measurement was identified.

<Inputs to regional workshops>
The progress and outcomes of the studies were shared in annual regional workshops where GHG inventory experts such as government officials and scientists of other countries in Asia attended. The inputs from the pilot studies stimulated discussion in the workshops and contributed to an increased body of knowledge on inventories in the region.

Relevance to the APN CAPaBLE Programme and its Objectives

The project resulted in enhancing the scientific capacity of Cambodia and Thailand to improve their GHG inventories which play a crucial role in realizing the sustainable development of the countries in relation to the climate change problems. It also succeeded in developing the scientific capacity of young scientists and students by deeply involving them in the pilot study in Thailand. Therefore, it can be concluded that the project perfectly matched with the theme of APN CAPaBLE Programme and fulfilled its purposes.

Self evaluation

Thanks to the close collaboration and enthusiasm of the project participants from three different countries, the project could attain almost all of its original objectives satisfactorily. In parallel to implementing research activities in Cambodia and Thailand, the progress and outcomes of the studies were regularly shared among the inventory experts of the region in regional workshops, which linked the project activities and outsiders while it was being implemented. Overall, we consider the project was valuable and unique in a sense that it targeted the capacity enhancement for the improvement of GHG inventories, which is a requirement under the UNFCCC and could possibly be learnt by other countries that are parties to the UNFCCC.

Potential for further work

The project participants, including the project proponents and collaborators, voluntarily agreed to make a full report of the three-year project activities after the end of the project. The report will become available to outsiders.

The established network among the project participants is expected to be kept through other related works in the future which are being planned (e.g. the 4th WGIA in 2007 to be sponsored by the Ministry of the Environment, Japan).

Publications

- Report of the meeting for the pilot study in Cambodia in Year 1
- Report of the first training for the pilot study in Thailand in Year 1
- Report of the training for the pilot study in Cambodia in Year 2
- Report of the second training for the pilot study in Thailand in Year 2
- Report of the third training for the pilot study in Thailand in Year 2
- Report of the activities of the pilot study in Cambodia in Year 2
- Report of the activities of the pilot study in Thailand in Year 2
- Report of the training for the pilot study in Cambodia in Year 3
- Report of the training for the pilot study in Thailand in Year 3
- Report of the activities of the pilot study in Cambodia in Year 3
- Proceedings for the 2nd Workshop on GHG Inventories in Asia Region

Acknowledgments

The project leader and other researchers and experts involved in the project activities either as a project proponent or collaborator would like to express their most gratitude to APN for its support during the three year of the project period. They would also like to extend their appreciation to the Ministry of the Environment of Japan for providing opportunities to the project to share its progress and outcomes regularly in regional workshops, known as “the Workshops on GHG Inventories in Asia Region”.

Dr. Nobuya Mizoue, Associate Professor of Department of Forest and Forest Products Sciences, Faculty of Agriculture, Kyusyu University, provided guidance on the forest measurement training implemented in Cambodia in Year 2. Dr. Masato Yamada of the Research Center for Material Cycles and Waste Management of NIES guided the landfill measurement in Thailand with his research team. Dr. Gen Inoue and Dr. Hiroshi Suto of the Center for Global Environmental Research of NIES and Dr. Kiyoshi Sawano of the Global Environmental Forum substantially assisted the construction and application of the semiconductor sensor used in the pilot study in Thailand. Lastly, Ms. Masako White of the Greenhouse Gas Inventory Office of Japan at NIES supported the project enormously by mainly carrying out its administrative work. Their supports for the project were indispensable for the success of the project activities and were highly appreciated by the entire project team.

Technical Report

Abstract

The improvement of quality of greenhouse gas (GHG) inventories is important for developing countries to prioritise their countermeasures against the adverse impacts and threats of climate change. This project demonstrated the comprehensive and source-specific approaches for the improvement of inventories by conducting pilot studies in Cambodia and Thailand, respectively. The major outcomes of the pilot studies were related to: the country-specific emission/removal factors for the emissions and removals from forest land use, rice paddies, and landfills; more representative activity data; the new estimation of inventories. The results of the pilot studies were shared in regional workshops annually.

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1 Introduction

Increase of emissions of greenhouse gases (GHG) has been the primary cause of global climate change and its impacts, like sea level rise and regional climate variability. Developing countries are particularly vulnerable to these adverse impacts and threats of climate change. Therefore, GHG inventories that can provide accurate knowledge of GHG emissions/removals trends are critically important for those countries to prioritise their countermeasures, which directly relates to their sustainable development.

In the Asia region, it is known that the lack of realistic emission factors and activity data is one of the constraints to develop accurate inventories. Moreover, despite the fact that the degree of development of inventories varies widely among countries, forums for neighbouring countries to exchange information and experience have not been established enough.

The ultimate goals of this project are to clarify the methodology for effectively improving the quality of inventories of countries in the Asia region and enhance the regional contribution to the related international efforts. To attain this goal, the project will aim to: a) carry out pilot studies on improvement of GHG inventories for effective countermeasures; b) make sustainable systems to develop GHG inventories with well organised contribution from researchers and government officials; c) provide more realistic emission factors reflecting country and regional conditions; d) exchange information and experiences to obtain accurate activity data; e) clarify the direction to apply the methodologies developed in the pilot studies to other neighbouring countries; f) enhance involvement and leadership in the related international activities; and g) provide policy makers with basic information to formulate and implement measures.

2 Methodology

2.1 Overall Methodology

To accomplish the objectives of the project, as listed above, the overall methodology of the project consists of three elements:

(1) *Comprehensive approach in a pilot study in Cambodia:*

This approach initially studies the entire aspects of the country's inventories to select the priority source/sink categories in inventories to be targeted for improvement. This approach was adopted in a pilot study in Cambodia.

(2) *Source-specific approach in a pilot study in Thailand:*

Taking speciality available into consideration, the approach focuses on particular source/sink categories in inventories for improvement. The approach was demonstrated in a pilot study in Thailand.

(3) *Inputs to regional workshops:*

The progress and outcomes of the pilot studies mentioned above are shared and discussed in annual regional workshops, "The Workshops on GHG Inventories in Asia Region (WGIA)", where experts from other neighbouring countries attended.

2.2 Methodologies in pilot studies

2.2.1 Pilot study in Cambodia

i) Summary of the methodology

By applying *the Good Practice Guidance for Land Use, Land-Use Change and Forestry* (GPG-LULUCF) of the Intergovernmental Panel on Climate Change (IPCC), the key source/sink categories of Cambodia's 1994 inventories were analysed and the priority areas for improvement were identified (*see Table 2-1*). Since the majority of the emission/removal factors and activity data, identified as the proprieties, did not include enough country-specific information, the study determined to conduct the following activities to produce those prioritised parameters to improve the quality of Cambodia's GHG inventories:

- To produce the country-specific values of aboveground biomass and annual growth rate of the major forest types, classified as key source/sink categories, by conducting forest measurements
- To estimate the activity data for the year 2000 based on the data that are the most available
- To develop the inventories for 2000 using the produced emission/removal factors and estimated activity data
- To use the GPG-LULUCF wherever it is relevant and can be applied

The study also prepared a well-structured file system following *the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* of the IPCC.

Table 2-1. List of prioritised parameters for improvement in the Cambodia's 1994 inventories, identified based on the key source/sink category analysis introduced in the GPG-LULUCF

IPCC Source Category		**Direct GHGs**	Prioritised parameters for improvement
5A Changes in Forest / Woody Biomass	Forest - Deciduous	CO_2	Forest area; annual growth rate
5A Changes in Forest / Woody Biomass	Forest - Evergreen	CO_2	Forest area; annual growth rate
5B Forest & Grassland Conversion	Biomass-Decay-Forest - Secondary/Regrowth	CO_2	Above ground biomass, fraction of biomass left to decay
5A Changes in Forest / Woody Biomass	Forest - Mixed&Coniferous	CO_2	Forest area; annual growth rate
5B Forest & Grassland Conversion	On-Site-Burning-Forest - Secondary/Regrowth	CO_2	Above ground biomass, fraction of biomass left to burn on site
5A Changes in Forest / Woody Biomass	Roundwood Harvested	CO_2	Wood harvested and biomass conversion factor

ii) Forest measurements

The methodology of the forest measurements was based on Hairiah K. et al. (2001) and is presented in the Appendix section (*see Table 2-2*). Non-destructive sampling for trees, including both living and dead trees, and destructive sampling for litter and undergrowth layer were conducted in the selected major forest types: Deciduous, Evergreen, and Secondary Forests.

2 plots were set up in two separate provinces for each of the forest types (*see Table 2-3*). Measurements were conducted in two different points in time, with approximate one-year interval, to calculate the annual growth rate of trees.

Table 2-2. Overview of the forest measurement methodology based on Hairiah K. et al. (2001)

Parameters		Methodology	Plot size
Living trees	Larger than 30 cm in diameter	Non-destructive sampling (i.e. Measurement of diameter)	20*100 m
	Larger than 5 cm and smaller than 30 cm in diameter	Non-destructive sampling (i.e. Measurement of diameter)	5*40 m
Necromass	All dead trees that have diameter greater than 5 cm and a length of > 0.5 m	Non-destructive sampling (i.e. Measurement of diameter)	5*40 m
Understorey	Trees smaller than 5 cm	Destructive sampling	1*1 m and 0.5*0.5 m
Litter	Coarse and fine litters	Destructive sampling	1*1 m and 0.5*0.5 m

Table 2-3. List of plots established and measurement time

Plot #	Forest type	Location	Dates of measurement	
			First time	Second time
A	Secondary Forest	Sihanoukvill	Mar 01, 2005	Feb. 07, 2006
B	Secondary Forest	Sihanoukvill	Mar 02, 2005	Feb. 05, 2006
C	Secondary Forest	Siem Reap	Mar 07, 2005	Jan. 28, 2006
D	Secondary Forest	Siem Reap	Mar 08, 2005	Jan. 26, 2006
E	Deciduous Forest	Preash Vihear	Mar 12, 2005	Jan. 23, 2006
F	Deciduous Forest	Preash Vihear	Mar 13, 2005	Jan. 21, 2006
G	Evergreen Forest	Kratie	Mar 24, 2005	Jan. 18, 2006
H	Evergreen Forest	Kratie	Mar 25, 2005	Jan. 17, 2006
I	Deciduous Forest	Kratie	Mar 27, 2005	Jan. 15, 2006
J	Deciduous Forest	Kratie	Mar 13, 2005	Jan. 13, 2006
K	Evergreen Forest	Kampot	Mar 30, 2005	Feb. 01, 2006
L	Evergreen Forest	Kampot	Mar 31, 2005	Feb. 03, 2006

iii) Aboveground biomass and annual growth rate of the major forest types

The GPG-LULUCF defines aboveground biomass as "all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage", which means “living tress” and “understorey” under the measurement of this study are counted as part of above ground biomass. The aboveground biomass of living trees was estimated following the biomass regression equation of Brown (1997) and that of understorey is measured by destructive sampling.

Biomass regression equation used to estimate the biomass of living trees:

$$\mathbf{Y = 42.69-12.800(D)+1.242(D^2)}$$

Where: Y = aboveground biomass
D= diameter at breast height

The annual growth rate of the forests is estimated as the difference of aboveground biomass between the measurements of the first and second time.

iv) Activity data including land use areas for 2000

The areas of land use categories defined in the GPG-LULUCF were estimated for the beginning and end of the year 2000 based on the linear extrapolation method with the data provided by GTZ/MRC for 1992/93 and 1996/97 (DoFW, 1999), which are the most available in the country. A number of assumptions, which are likely to be the most realistic, were developed to estimate the areas of land use categories converted to another land use.

Other than the land use areas, data on wood products and fuelwood consumption were newly estimated through literature survey.

v) New inventory for 2000

Based on the data which were obtained and estimated from forest measurements, the past inventory studies, and other literature sources, emissions and removals from the LULUCF sector for the year 2000 were calculated using the worksheets developed based on the IPCC’s 1996 Guidelines. A full report including the explantation of all the procedures taken to estimate the emissions and removals was then prepared.

2.2.2 Pilot study in Thailand

i) Summary of the methodology

Conventionally, the ambient level concentration of CH_4 emitted from rice fields is quantified by a gas chromatograph equipped with flame ionization detector (GC-FID). While it is recognised that this GC method yields highly reliable results, its application has been limited, particularly in remote areas, because of its non-mobile characteristics, relatively high cost, and high operation skill requirement.

This study constructed the semiconductor sensor, developed by NIES, and tested its capability for the reliable measurement of methane flux from rice fields. The use of this semiconductor sensor for the measurement has the advantage of more convenient, less time consuming, and more mobile than the conventional GC method. Once the capability of the semiconductor sensor was confirmed, it was used to develop the emission factors for CH_4 emissions from irrigated rice fields under different management modes and rainfed rice fields.

In addition, since few studies have ever been conducted in Thailand to measure methane flux from landfills, the current study tested the application of the semiconductor sensor and the laser gas detector (SA3C15A, Anritsu Corp., Atsugi, Japan) to measure methane flux from landfills.

ii) Construction and examination of the semiconductor sensor

A series of training on assembling sensor unit and applying it was performed, as indicated below:

- One-month training at NIES mainly in order to assemble the methane sensor and understand the basic principles of its operation.
- Nine-day training at NIES to obtain knowledge and experiences for operating and using the sensor unit for *in situ* methane and CO_2 flux measurements.
- One-week training at KMUTT to fully check the function of the sensor instrument after transport from NIES to KMUTT and to operate the sensor instrument for emission measurement in Thai rice paddies

iii) Measurement of methane emission from paddy field

The IPCC's 1996 Guidelines provides the default values of emission factors from various types of rice field managements. Following this IPCC guidelines, the current experiment was designed to estimate the emission factors as affected by fertilization modes. The soil at the site is classified as Bangkok soil series. For irrigated fields, three treatments with two plots for each were made. These treatments included no fertilizer application (Control; CT), farmyard manure (Poultry, FM) applied at 1 ton ha^{-1}, and chemical fertilizer application (CM) at 190 kg N ha^{-1}. For each treatment, two subplots (20 x 20 m each) were made and for each subplot two locations were selected for chamber placement and flux measurement. Rice seeds were sown on April 22, 2005. Chemical fertilizer (urea) was applied twice at 14 and 26 days after seed sowing (DAS). Farmyard manure was applied only once at the beginning. Rice in all treatments was harvested on 30 July 2005 or 99 DAS. No drainage was performed during the investigation period. However, to facilitate harvest by farm machinery, fields were drained from 79 DAS onwards.

The second crop was started on August 27, 2005 on the same locations as that of the first crop. All field settings and cultivation practices were the same as those for the first crop. Rice was harvested on December 9, 2005.

The third crop was started in January 8, 2006. All field practices and managements were remained in the same manners as those for the first and second crops. The field was harvested on April 26, 2006.

Rain fed rice field was also designed to include the three treatments mentioned above. At this site, rain came later than usual (normally rainfall begins around May) and it was until August 15, 2005 that rice seeds were sown. However, during the first two weeks, that areas including the sampling plots were flooded due to heavy rainfall, experiment was delayed until September 5, 2005. Field management and practices were the same as mentioned above. However, there was no drainage and water level was controlled mainly by rainfall. Rice was harvested on December 15 or 122 DAS but measurement was conducted only to November 26, 2005 due to some damages happened to the sensor unit. This problem was fixed later but not before rice was harvested.

During gas measurement by the sensor unit, a separate set of gas samples were also collected using the disposable syringe and then determined by gas chromatography (GC). This practice allowed the comparison between sensor and the conventional GC flux measurement results.

iv) Measurement of methane emission from landfill

The sensor unit, used for the measurement flux from rice fields, and the laser gas detector were tested to measure methane emission from landfill site during October and November, 2005. The measurement results of these two techniques were then compared with the results of conventional disposable syringe-GC and tedlar bag-GC. The Hua – Hin landfill site that was used to study in this experiment covers a surface area of 44,160 m^2. It is located close to the Hua – Hin city, 200 km south of Bangkok. The site has been operating since 1996 with approximately 70 tons/day from Hua – Hin and adjacent area. The waste deposited there was primarily household waste. The waste in place is about 101,000 tons. The Hua - Hin waste compose of paper 31.77%, textile 0.97%, food waste 48.36%, green waste 0.18%, plastic waste 17.12%, bone 1.23%, rubber 0.02%, and metal 0.35%.

3 Results & Discussion

3.1 Pilot study in Cambodia

3.1.1 Aboveground biomass and annual growth rates

The values of aboveground biomass and annual growth rates adopted in this study are shown in Table 3-1. The values for forest types that were not measured under this study were based on the previous inventory studies implemented in Cambodia: *the Cambodia's initial national communication (1st NC)* and *the Cambodia Climate Change Enabling Activity Project's Phase 2 (CCEAP-2)*.

Though the definitions of “above ground biomass” vary among different studies considered under this study, the values of the aboveground biomass of Evergreen and Deciduous estimated for this study based on forest measurements are noticeably large compared to the values of the previous inventory studies and other papers (Top et al., 2004; Brown, 1997).

The figure of the annual growth rate of Evergreen measured in this study is only 0.03 t dm per hectare, which is smaller than those estimated in the past inventory studies. One of the possible reasons could be a significant reduction of the biomass of understorey from the first-time to the second-time measurement observed under this study, which as a result cancelled the annual growth of the biomass in living trees. While the estimated annual growth rate of Secondary (Forest Regrowth) appears to be relatively large compared to the past inventory studies and other literature, that of Deciduous seems reasonable (Top et al., 2004).

Table 3-1. Estimated aboveground biomass and annual growth rate of forests by forest types

Land use category	Aboveground biomass (t dm/ha)			Annual growth rate (t dm/ha/yr)		
	Present study	1st NC	CCEAP-2	Present study	1st NC	CCEAP-2
Forest Land						
Evergreen	407(1)	295	200	0.03(1)	3.00	2.50
Semi-evergreen	200	370	250	3.00	4.20	3.00
Deciduous	278 (1)	120	100	4.13(1)	3.60	2.00
Forest Regrowth	167.7 (1)	190	120	4.55(1)	2.83	2.50
Inundated	70	70	70	2.00	2.98	2.00
Mangrove	150	175	150	3.00	3.00	3.00
Forest Plantation	100	80	100	6.70	6.68	6.70
Cropland						
Mosaic of Cropping (<30%)	30	n/a	40	1.50	n/a	1.50
Mosaic of Cropping (>30%)	75	n/a	75	0.50	n/a	0.50
Agricultural Land	n/a	n/a	n/a	n/a	n/a	n/a
Grassland						
Wood/Shrubland Evergreen	70	70	70	1.00	n/a	1.00
Grassland	5	n/a	5	0.20	0.50	0.20
Bamboo	n/a	n/a	n/a	n/a	1.50	n/a
Wood/Shrubland Dry	50	n/a	50	0.70	n/a	0.70
Wood/Shrubland Inundated	40	n/a	40	0.50	n/a	0.50
Wetlands						
Wetland	n/a	n/a	n/a	n/a	n/a	n/a
Settlements						
Urban/Built-Over Area	n/a	n/a	n/a	n/a	n/a	n/a
Other Land						
Barren Land	n/a	n/a	n/a	n/a	n/a	n/a
Rocks	n/a	n/a	n/a	n/a	n/a	n/a
Water	n/a	n/a	n/a	n/a	n/a	n/a
Other	n/a	n/a	n/a	n/a	n/a	n/a

(1) Estimated based on the results of forest measurements conducted in the present study.

3.1.2 Activity data including land use categories under the GPG-LULUCF

The areas of land use categories, as defined in the GPG-LULUCF, were estimated for the beginning and end of the year 2000 (*see table 3-2*).

Table 3-2. Estimated areas of land use categories, defined in the GPG-LULUCF, in 2000

Land use category	Initial land use estimated area (ha)	Final land use estimated area (ha)	Land-use change 00	
			Area (ha)	% (F/D)
Forest Land	**10,527,462.0**	**10,472,090.0**	**-55,372.0**	**-0.5%**
Evergreen	3,960,140.0	3,946,850.5	-13,289.5	-0.3%
Semi-evergreen	1,490,717.5	1,483,413.3	-7,304.3	-0.5%
Deciduous	4,246,993.5	4,229,791.8	-17,201.8	-0.4%
Forest Regrowth	343,486.5	328,131.3	-15,355.3	-4.5%
Inundated	328,222.5	324,680.3	-3,542.3	-1.1%
Mangrove	70,418.0	69,209.5	-1,208.5	-1.7%
Forest Plantation	87,484.0	90,013.5	2,529.5	2.9%
Cropland	**4,498,390.5**	**4,582,175.8**	**83,785.3**	**1.9%**
Mosaic of Cropping (<30%)	328,293.0	349,862.0	21,569.0	6.6%
Mosaic of Cropping (>30%)	163,472.0	173,310.0	9,838.0	6.0%
Agricultural Land	4,006,625.5	4,059,003.8	52,378.3	1.3%
Grassland	**2,516,107.5**	**2,483,250.3**	**-32,857.3**	**-1.3%**
Wood/Shrubland Evergreen	538,125.5	534,637.8	-3,487.8	-0.6%
Grassland	494,562.5	497,522.3	2,959.8	0.6%
Bamboo	34,483.0	34,859.5	376.5	1.1%
Wood/Shrubland Dry	1,114,180.5	1,088,582.3	-25,598.3	-2.3%
Wood/Shrubland Inundated	334,756.0	327,648.5	-7,107.5	-2.1%
Wetlands	**79,470.5**	**77,535.8**	**-1,934.8**	**-2.4%**
Wetland	79,470.5	77,535.8	-1,934.8	-2.4%
Settlements	**28,110.0**	**28,357.5**	**247.5**	**0.9%**
Urban/Built-Over Area	28,110.0	28,357.5	247.5	0.9%
Other Land	**504,191.0**	**510,696.5**	**6,505.5**	**1.3%**
Barren Land	19,659.0	20,420.5	761.5	3.9%
Rocks	2,149.0	2,149.0	0.0	0.0%
Water	480,627.0	486,371.0	5,744.0	1.2%
Other	1,756.0	1,756.0	0.0	0.0%
Total	**18,153,731.5**	**18,154,105.8**	**374.3**	**0.0%**

The areas of land use categories converted to another land use in 2000 were estimated based on various assumptions considered to be the most realistic (*see Table 3-3*).

In this estimation, it was assumed that only the difference of areas of specific land use categories between the initial and final point in time, (i.e. the beginning and end of 2000) experienced land conversion. For example, it was estimated that the land area of Forest Land was decreased by around 55,372 hectares in 2000. With this case, we assumed that this decreased area of Forest Land went through land use conversion and the rest of Forest Land area remained as Forest Land.

In the Initial National Communication (MoEC, 2002), total wood harvest in 1994 was estimated to be about 1.5 million m^3, similar to round wood production of 1993 and 1995. This data might not consider wood production from illegal logging, while many reports stated that illegal logging accounted for most of the total round wood in Cambodia (Bottomley, 2000). Based on official data, the total wood production from 1960 to 1995 was about 8,766,000 m^3. In 2000, the total production of round logs was reported at 187,488 m^3, which is being used under the current study.

The fuelwood consumption for 2000 is estimated based on the average household use of fuelwood. Taking consumption of households that use fuelwood 1.54 kg/day and the percentage of household using fuelwood 90% (NIS, 1999), the total fuelwood consumption in 2000 is estimated at 1,107,000 tonne.

Table3-3. Estimated areas of land use categories converted to another land use in 2000 with various assumptions used, following the GPG-LULUCF

Land conversion concerned (Area in hectare)		Description of assumption
Before	After	
Grassland (2,529.5)	Forestland (2,529.5)	It is difficult to predict forest planting was conducted after destroying existing forests. Considering ecological reasons, it is also difficult to plant trees in wetlands. Hence, it is assumed that all plantations were established in grasslands.
Forestland (3,336.3)	Grassland (3,336.3)	It is the most realistic to assume grassland was established by converting forestland.
Grassland (247.5)	Settlements (247.5)	It is the most realistic to assume settlements was established by converting grassland.
Forestland (54,565.3)	Cropland (83,785.3)	The remaining area of forestland that went through conversion was reported here.
Grassland (29,220)		It is assumed that the rest of area of cropland converted from different land uses was area converted from grassland.
Grassland (4,196.5)	Other land (6505.5)	The remaining area of grassland that went through conversion was reported here.
Wetlands (2309.0)		It is assumed that the rest of area of other land converted from different land uses was area converted from wetlands.

3.1.3 Developed inventory for 2000

The emissions and removals from the LULUCF sector in Cambodia for 2000 were estimated by applying the data developed and collected under this study to the well-structured worksheets, which were prepared based on the IPCC's 1996 Guidelines (*see Table 3-4*). The total removals of the sector were dramatically decreased if compared with the 1994 GHG inventory: 17,906 kt-CO_2 eq. for 1994 and 7,297 kt-CO_2 eq. for 2000. In the estimation for 2000, the removals due to changes in "forest/woody biomass" are 50,090.95 kt-CO_2 eq. and the emissions from "forest/land use change" are 42,793 kt-CO_2 eq.

Table3-4. Summary of the estimated GHG emissions and removals from the LULUCF sector for 2000

Sub Sector	C Release (+) and Uptake (-) (kt C)	CO_2 Emission (+) and Removal (-) (kt CO_2)	CH_4 (kt)	CO (kt)	N_2O (kt)	NOx (kt)
Change in Forest/Woody Biomass						
Biomass Growth	-13,536.31	-49,633.15				
Roundwood Harvests	-124.85	-457.80				
Abandoned Lands	Not Determined	Not Determined				
Subsector Subtotal	**-13,661.17**	**-50,090.95**				
Forest/Land Use Change						
On Site Burning	2,826.80	10,364.93	45.23	395.75	0.31	11.24
Off Site Burning	706.70	2,591.23				
Decay	7,852.22	28,791.48				
Soil Carbon Emissions	Not Determined	Not Determined				
Subsector SubTotal	**11,385.72**	**41,747.65**				
LULUCF Sector Subtotal	**-2,275.45**	**-8,343.31**	**45.23**	**395.75**	**0.31**	**11.24**
Equivalent CO2 Emissions (kt)		**-8,343.31**	**949.80**		**96.39**	
TOTAL CO_2 Equivalent Emissions (kt 'CO_2') =		**-7,297.11**				

The full report, including the explanation of all the procedure followed to reach the above estimation results, was also compiled. Updates on the report will be made between the completion of this study and the final stage of their preparation of the second national communication. The outline of the full report is:

i) Introduction
ii) History of LULUCF in Cambodia
iii) Application of GPG-LULUCF
iv) Emission and removal factor
v) Forest land
vi) Estimation of GHG emission/removal
vii) Conclusion

3.2 Pilot study in Thailand

3.2.1 Construction and examination of the semiconductor sensor

During March 2004, the portable system for measuring CH_4 and CO_2 at ambient concentration levels was assembled from the materials prepared by NIES. The system consists of three main parts; detection unit, control unit, and display and record unit. This first period of training was focused mainly on assembling and testing the detection and control units. Each component was assembled and its function and operation were tested. Detection of CH_4 is enabled by using SnO_2-based sensor housed in a well temperature-controlled box. The gas sample to be measured was supplied to the sensor by pumping at appropriate rate. To remove interferences from the air stream, filters of various size and specification, and water traps were installed. Since the main interference is water, emphasis was given on how water can be removed effectively. Application of Nafion tube, magnesium percholate, and phosphorus pentaoxide resulted in efficient removal of water. Other interferences such as CO and H_2 were removed by applying the catalyst Pd and Pt.

Using this sensor unit, methane in the air stream was detected by sensor based on chemical reaction with the chemisorbed oxygen molecule. Such reaction resulted in the increase in overall conductivity of the sensor cell. This change in conductivity was measured as resistance change of the sensor electrodes in reference to resistance generated by the known concentration of CH_4 gas standards. Since the change in conductance is proportional to the partial pressure of CH_4 gas in the air stream, its quantitative analysis is rendered possible. Typical signal output is illustrated in Fig. 3-1. In the same aliquot of air, CO_2 concentration could also be quantified. This was achieved by connecting the outlet air stream from the CH_4 sensor unit to the NDIR (non-dispersive infrared)-CO_2 measuring unit. The output from both CH_4 sensor and NDIR units were then recorded by the appropriate data recorder.

Calibrations of the assembled instrument were done by using six different concentrations of standard CH_4 and CO_2 gases. Over the test periods of about three days, the results show that highly reproducible outputs were obtained and errors associated with CO_2 and CH_4 concentration measurements were below 0.15 ppm and 10 ppb, respectively. Example of calibration curve for methane is given in Fig. 3-2.

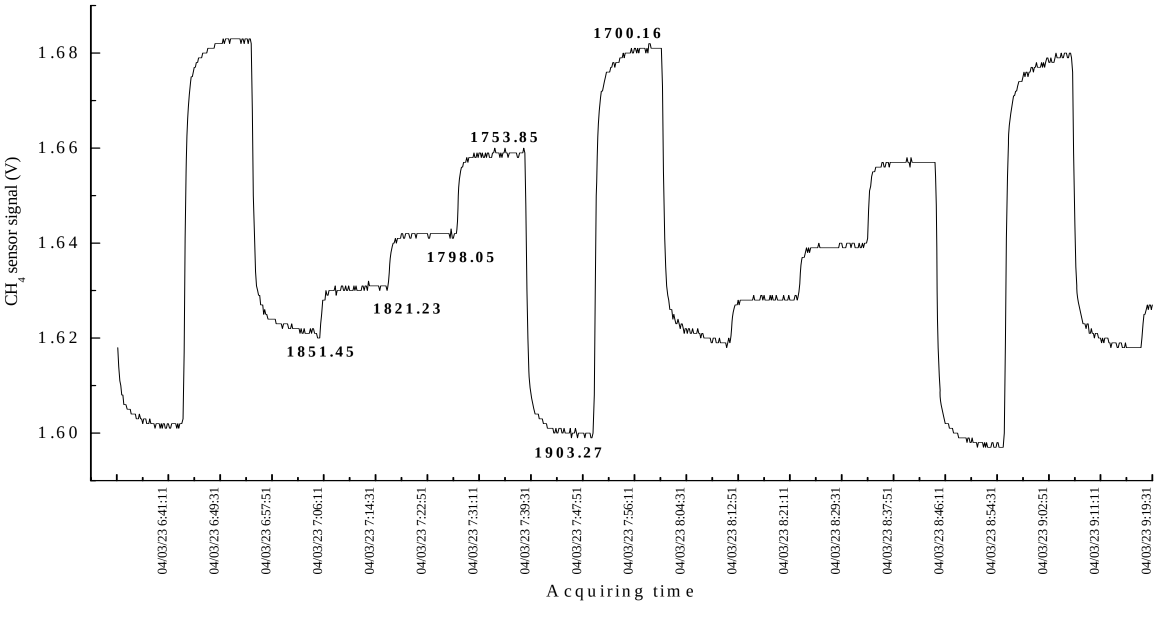

Fig. 3-1. CH_4 signal responded to six different concentrations of CH_4 standard at 10 min sampling interval. Values shown are concentrations in ppbv.

From the test results, it was concluded that the assembling of sensor unit was successful. It can be effectively and reliably applied to measure concentration change of both greenhouse gases. However, application of this instrument needs a thorough understanding of the operation system and this research training has supplied such basic know-how and necessary knowledge for effective operation and maintenance.

In August 2004, operation of a mobile unit for measuring methane and CO_2 flux was practiced. This unit was successfully tested for stability, measurement accuracy and reproducibility and used for *in situ* flux measurements. The measured parameters were stored in datalogger and subsequently transferred to working computer for data analysis.

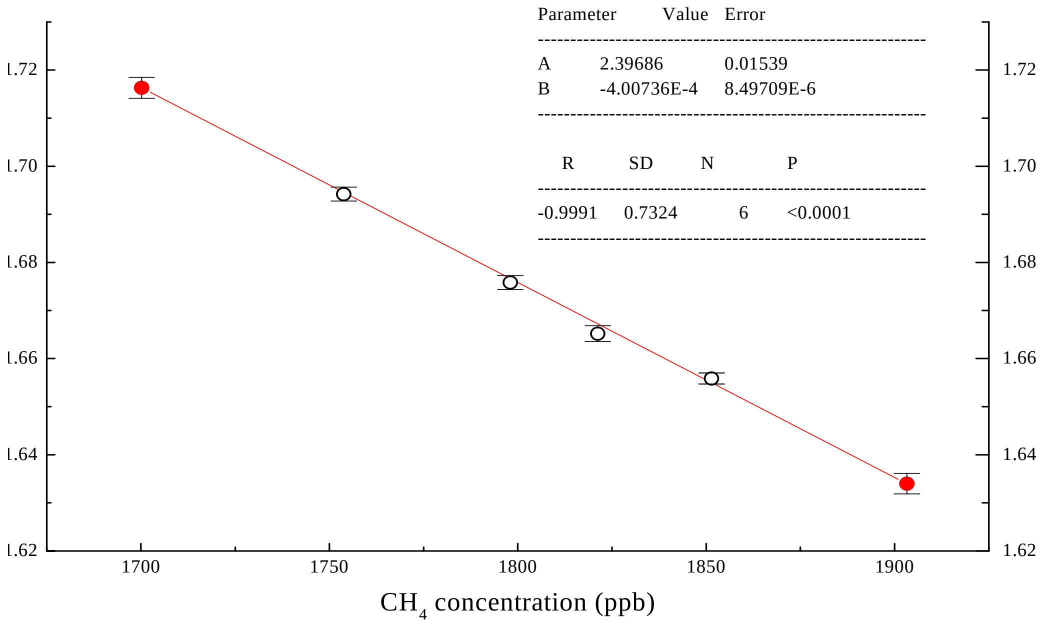

Fig. 3-2. Relationship between CH_4 sensor signal outputs and CH_4 concentrations (averaged over 3 measurement cycles, not include the drift correction).

The results obtained indicate that the sensor unit can be used effectively to measure methane and CO_2 flux in paddy field. Moisture was removed effectively by the trapping components. Thus, high humidity when using chamber method to measure methane flux in paddy field does not cause a significant effect on sensor stability. Measuring unit is proved to be highly stable and can detect rapidly even a small change of methane and CO_2 concentrations inside the chamber headspace. A significantly linear relationship between methane/CO_2 concentrations and chamber enclosure time was observed during the 30-min sampling period. Shorter enclosure time was also possible.

3.2.2 Methane emission from irrigated paddy fields

i) Results of the first crop season

After on-site testing and validation of the methane sensor unit, the sensor was used to measure CH_4 and CO_2 emission in Thai paddy fields. Three CH_4 and CO_2 standard gases with methane concentration of 1, 2 and 6 ppmv and CO_2 concentration of 382, 415 and 443 ppmv was used to produce a calibration curve. Results of methane and CO_2 flux measurements during the first crop are summarized in Table 3-5. A multi-peak characteristic was observed in Control and Chemical fertilizer plot. However, in manure plots only a single peak appeared around 50-60 DAS. In all treatments, the maximum average flux was about 30-35 mg m^{-2} hr^{-1}. There were large variations in flux both between two subplots within each plot (as seen from the large S.D.).

Unlike methane, CO_2 flux showed smaller variation among plots and treatments. The fluxes were still relatively high even at the end of growing season. The total fluxes integrated over rice growing season were (mean of two plots±S.D.) 2420.87±138.36, 2308.67±323.33, 2700.23±300.99 g CO_2 m^{-2} in the Control, Manure and Chemical fertilizer plots, respectively.

ii) Results of the second crop season

During this period, measurement was interrupted due to problem happened with the sensor unit. This was recognized after few times of field trips and continued from the mid of season until rice harvest. This problem was solved after replacing and reconnecting the moisture trapping unit to the sensor. Thus, the emission values obtained during the second crop were considered incomplete and thus cannot be used as representative for that cropping. The emission values are shown in Table 3-6.

Table 3-5. Summary of rice yield, methane and CO_2 fluxes during the first crop (April-August 2005) in irrigated paddy field. The values are average±S.D. of two plots

Treatment	Plot	CH_4 flux (gCH_4/m^2/crop)	CO_2 flux (gCO_2/m^2/crop)	Rice Yield (g/m^2)
Control (no fertilizer)	1	-	2518.70	437.5
	2	8.52	2323.03	425.0
	Average±SD	**8.52**	**2420.87±138.36**	**431.25±8.84**
Manure	1	10.95	2080.04	487.5
	2	16.71	2537.30	450.0
	Average±SD	**13.83±4.07**	**2308.67±323.33**	**468.75±26.52**
Urea	1	14.58	2913.06	532.5
	2	7.38	2487.40	522.5
	Average±SD	**10.98±5.09**	**2700.23±300.99**	**525.50±7.07**

Table 3-6. Summary of rice yield, methane and CO_2 fluxes during the second crop (August-December) 2005 in irrigated paddy field. The values are average±S.D. of two plots

Treatment	Plot	CH_4 flux (gCH_4/m^2/crop)	CO_2 flux (gCO_2/m^2/crop)	Rice Yield (g/m^2)
Control (no fertilizer)	1	0.37	123.66	265
	2	0.28	111.92	265
	Average±SD	**0.33±0.04**	**117.79±5.87**	**265.00±0.00**
Manure	1	0.20	104.28	275
	2	0.44	79.20	305
	Average±SD	**0.32±0.17**	**91.74±12.54**	**290±12.50**
Urea	1	0.30	134.90	325
	2	0.28	85.05	305
	Average±SD	**0.29±0.01**	**104.64±19.59**	**315±10.00**

iii) Results of the third crop season

Table 3-7 gives the amount of methane emission during the third crop season. The measurement was carried out in order to confirm the first crop because the second crop measurement was incomplete.

From methane flux measurements in irrigated rice fields, it can be concluded that methane emission varied greatly between years and between crops. Application of manure and chemical fertilizer increased methane emission 1.6 and 1.3 times compared with those without fertilizer in the first year. The effects of manure and chemical fertilization in the second and third crops are not clear and seems that these are less pronounced compared to that of the first crops.

Table 3-7. Summary of rice yield, methane, and CO2 fluxes during the third crop (Started in January 2006) in irrigated paddy field. The values are average±S.D. of two plots

Treatment	Plot	CH_4 flux ($gCH_4/m^2/crop$)	CO_2 flux ($gCO_2/m^2/crop$)	Rice Yield (g/m^2)
Control (no fertilizer)	1	2.81	3807.87	574.73
	2	3.31	3672.70	549.02
	Average±S.	**3.06±0.75**	**3740.28±67.59**	**561.88±12.86**
Manure	1	3.24	3778.30	475.40
	2	3.67	3743.56	500.49
	Average± S.E	**3.46±0.22**	**3760.93±17.37**	**487.95±12.55**
Urea	1	3.75	3975.50	596.39
	2	1.52	3554.69	566.14
	Average± S.E	**2.63±1.11**	**3765.09±210.41**	**581.27±15.12**

Since only the first and third crop results are considered complete, we therefore used these (Table 3-5 and 3-7) as the basis for comparison to other measurements in the past. Data shown in Table 3-8 indicate that our emission factors are generally in the lower ranges of those measured by Ministry of Science, Technology and Environment (MSTE, 2000) for National Greenhouse Gas Inventory 1994. The MSTE used these data as basis for calculating the scaling and emission factors for methane emission in Thailand. The discrepancy may arise either from true variations in emissions (e.g. different soil series and environmental conditions) or from the overestimated flux by the GC used in the past estimates over the newly introduced sensor technique (see Fig. 3-3). It is likely that fluxes estimated from measurements with different flux measurement intervals are varied when there are spatially and temporally large variations of emissions, which is commonly found in paddy fields. Thus, more frequent measurements are preferred if local circumstances permit to do so.

Table 3-8. Comparison of methane flux between those used for NC (Ministry of Science, Technology and Environment, 2000) by MSTE and the results obtained in this study, expressed in kgCH4/ha/day.

Source	Soil series	Field practice		
		CT	CF	OM
NC	**Irrigated rice**			
	-Rangsit	0.45	0.73	No data
	-Nakornpathom	1.13	2.32	No data
	-Roi-et	3.77	5.41	No data
	-Hang Dong	0.89	1.76	No data
	Rain fed*	1.248	No data	2.496
This study	**Irrigated rice**			
	-Bangkok-1st crop	0.86	1.10	1.40
	-Bangkok-3rd crop	0.33	0.28	0.37
	Rain fed*	0.05	0.04	0.08

*soil series for rain fed site is not available.

3.2.3 Methane emissions from rain fed paddy fields

Table 3-9 gives the emission estimated for rain fed rice paddy. Generally, the emissions were lower than those from the irrigated rice paddy. Emissions from manure plot were higher than those from no fertilizer and chemical fertilizer plots, which were similar to those obtained from the irrigated paddy field. Again, the emission magnitude obtained may not be considered as representative for the typical rain fed rice field, since there was flood during the early season and planting could begin only during the later dates. However, the information we obtained suggest for accurate emission inventory in the future, such factors may need to be included. The factors that interrupt plant growth and field managements may affect the inventory and cause the variations in emission both in time and space.

Table 3-9. Methane and CO_2 fluxes from the rain fed paddy fields. The values are average±S.D. of two plots.

Treatment	Plot	CH_4 flux (gCH_4/m^2/crop)	CO_2 flux (gCO_2/m^2/crop)	Rice Yield (g/m^2)
Control (no fertilizer)	1	0.55	69.71	498
	2	0.53	93.03	No data
	Average±SD	**0.54±0.01**	**81.37±11.66**	**498**
Manure	1	0.55	105.21	452
	2	1.03	76.17	644
	Average±SD	**0.79±0.24**	**90.69±14.52**	**548±96**
Urea	1	0.51	64.79	464
	2	0.44	92.25	561
	Average±SD	**0.48±0.04**	**78.52±13.73**	**513±48**

3.2.4 Comparing between the results from sensor and GC technique

In the past, methane fluxes from rice paddy were determined by using the close chamber and a subsequent determination of concentration by GC. However, emission measurement by the sensor would help improve inventory by shortening the sampling time and eliminating the sample analysis in the laboratory after the field trips. To validate that results obtained from the sensor are consistent with those of the conventional GC technique, gas samples were collected and analyzed by GC at the same time when the sensor was used. The relationships of flux data shown in Fig. 3-3 indicate good agreements of flux estimated by sensor and GC technique. Thus, it can be said that sensor can be used in place of the conventional GC method and this should help improve emission inventory, especially in the remote area where GC is not available for such purpose.

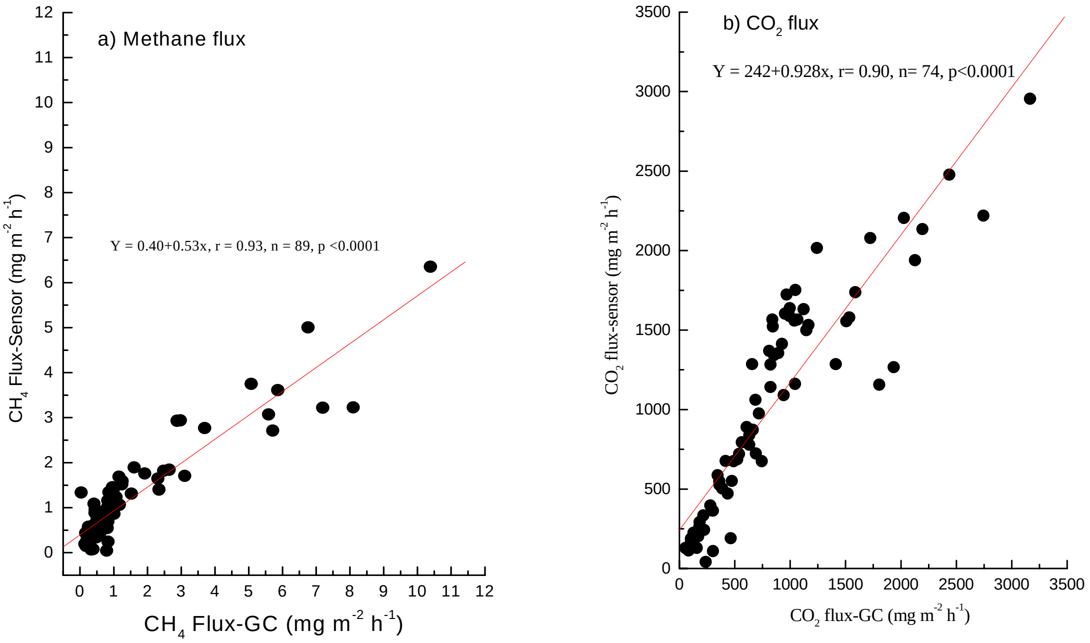

Fig.3-3. Methane (a) and CO_2 (b) fluxes compared between those measured by sensor and GC techniques.

became saturated rapidly, after chamber enclosure about 1-2 min. At low flux rate, there are relatively good agreements among various techniques used, however semiconductor sensor show its limitation of measurement on higher flux when compared to other technique.

The results from closed flux chamber method and laser gas detector method, as seen in Figure 3-5 show the good linear relationship with the R^2 = 0.84. The equation was Y (methane flux from GC method, gCH_4 m^{-2} day^{-1}) = 0.8424 x (methane flux from laser gas detector method, gCH_4 m^{-2} day^{-1}) + 16.618. We conclude that with high flux of methane emission such as landfill (0-300 $g/m^2/d$) laser gas detector and closed flux chamber can be the alternative method used with the deviation approximately 20 percent. Semiconductor methane sensor is not recommended to use in the landfill unless in the landfill known with few emission.

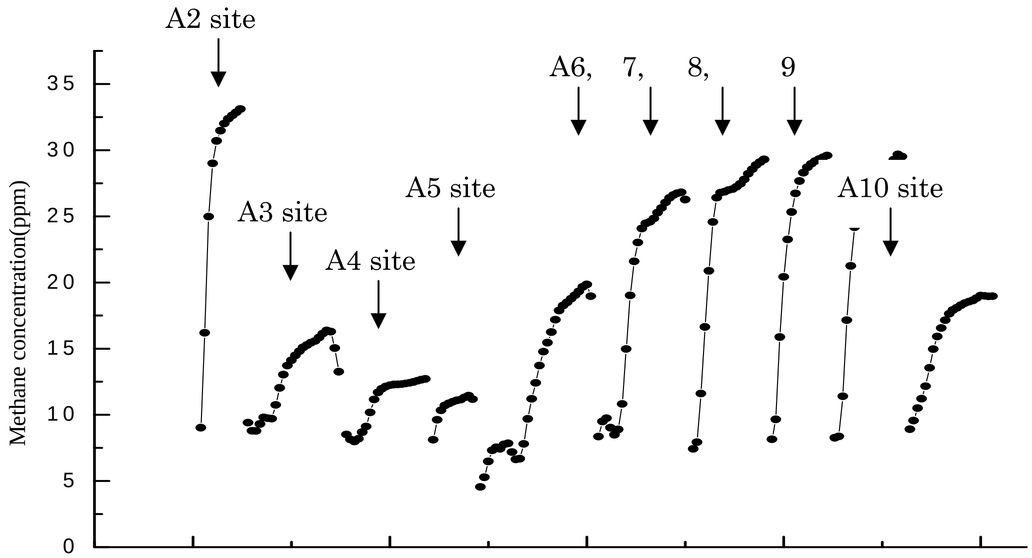

Fig. 3-4. Change of methane concentration inside the chamber measured by methane semiconductor sensor, Hau Hin landfill site, Thailand.

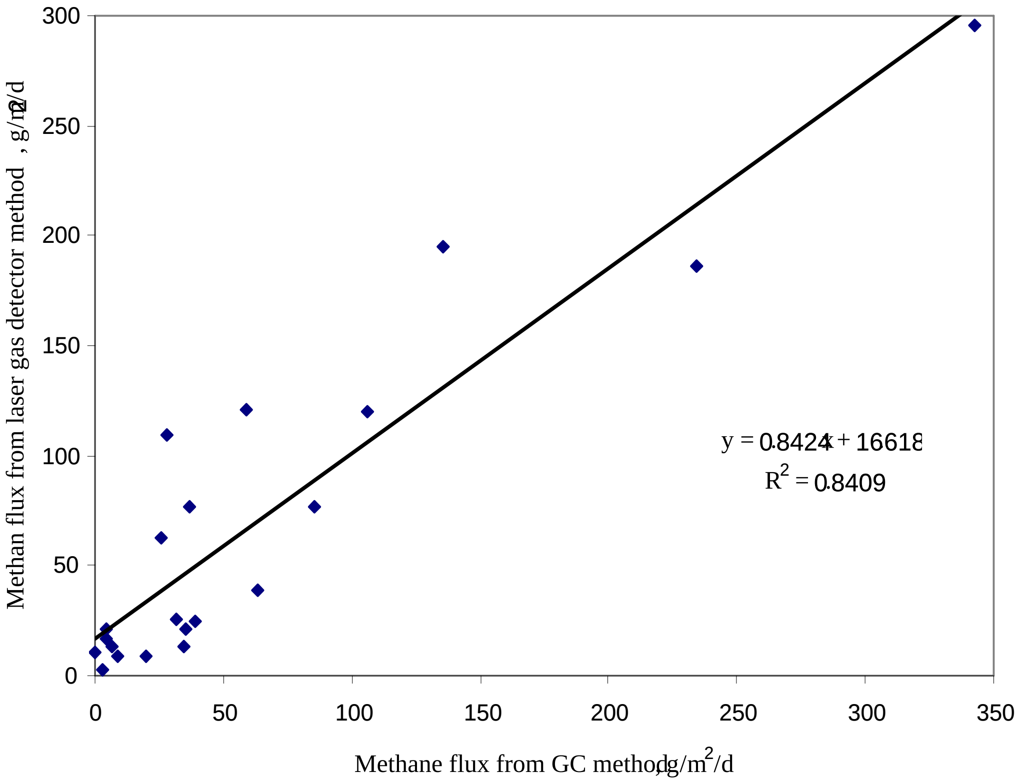

Fig. 3-5. The relationship between GC method and laser gas detector method.

3.3 Inputs to regional workshops

The progress and outcomes of the pilot studies in Cambodia and Thailand were reported in annual regional workshops, titled as "The Workshops on GHG Inventories in Asia Region (WGIA)". Those can be seen over the webpage of WGIA[1]. As examples of specific and on-going regional collaborative activities with the specific aim of the improvement of GHG inventories, the inputs from the pilot studies attracted high interests from the participants of WGIA and stimulated active discussion among them.

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[1] WGIA webpage: http://www-gio.nies.go.jp/wwd/wgia/wgiaindex-e.html.

4 Conclusions

In three years, the project generated a number of outputs that are directly or indirectly related to the objectives of this project, which are to:

a. Carry out pilot studies on improvement of GHG inventories for effective countermeasures
b. Make sustainable systems to develop GHG inventories with well organised contribution from researchers and government officials
c. Provide more realistic emission factors reflecting country and regional conditions
d. Exchange information and experiences to obtain accurate activity data
e. Clarify the direction to apply the methodologies developed in the pilot studies to other neighbouring countries
f. Enhance involvement and leadership in the related international activities
g. Provide policy makers with basic information to formulate and implement measures

The table below presents the concrete outputs generated out of this project by different scales (i.e. national, regional, and global scales) and the relevance of them to the individual project objectives.

Scale	Outputs	Relevance to the project objectives (a. to g.)
Cambodia	1. Developed a well-structured file system to prepare inventories, following the IPCC's 1996 Guidelines	**a, b** • Improved the sustainability of the system to prepare inventories
	2. Developed the local values of aboveground biomass and annual growth rate of the forests which are classified as key source/sink categories in the Cambodia's 1994 inventories	**a, c** • Improved the accuracy of estimation of emissions and removals • Established the technical capacity of the team to estimate the local values from direct measurements • Enhanced the understanding of the IPCC's GPG-LULUCF
	3. Estimated the emissions and removals of the LULUCF sector in 2000 using the developed local values and some other newly estimated activity data, such as forest areas, wood products, and fuelwood consumption	**a, b, d** • Improved the accuracy of estimation of emissions and removals • Enhanced the technical understanding of the team in the estimation methodology • Enhanced the understanding of the team in using the IPCC's GPG-LULUCF
	4. Prepared a comprehensive report for the Cambodia's LULUCF inventory for 2000, which could be used in its second national communication	**a, b** • Improved understanding and skills to report an inventory
Thailand	1. Constructed the semiconductor sensor unit and	**a, c** • Established the scientific and

	confirmed its capability to measure methane flux in rice fields reliably, through which the project collaborator obtained basic knowledge and skills to assemble, operate, and maintain the sensor unit	technical capacity of the team, including young scientists and students, in the use of the sensor and the understanding of methane flux measurement in rice fields
	2. Developed the local emission factors for methane emissions from irrigated rice fields and rainfed rice fields under different fertilization modes	**a, c** • Enhanced the scientific capacity of the team, including young scientists and students, in research on methane flux measurement from rice paddies and estimation of emission factors
	3. Identified the possibility of the new measurement methodology with the laser gas detector for methane flux measurement in landfills	**a, c** • Established the scientific and technical capacity of the team, including young scientists and students, in the use of the detector and the understanding of methane flux measurement in landfills • Enhanced the scientific capacity of the team, including young scientists and students, in research on methane flux measurement from landfills
Asia region	1. Informed the progress and results of the pilot studies annually and stimulated relevant discussion	**b, c, d, e, g** • Contributed to increasing a body of knowledge of experts in the region, including policy makers
Global	1. Developed some country-specific values which could be shared with other nations	**c, f** • Could contribute to improving inventories of other countries if the developed values become available publicly, for example, via the IPCC Emission Factor Database
	2. Demonstrated two case studies in Asia for the improvement of inventories	**e, f** • Could contribute to assisting other countries in doing the similar activities for the improvement of inventories if the information of activities is distributed broadly

5 Future Directions

5.1 Pilot studies

5.1.1 Pilot study in Cambodia

The pilot study in Cambodia measured the actual values of forest biomass and its growth per year, focusing on the major forest types in terms of the significance of their contribution to the national emissions and removals. Although it is a significant step that the study actually conducted the measurements, the more number of such measurements is desperately needed over time to generate more representative thus reliable local values. The uncertainty of collected data can also be assessed. Therefore, it is desired that the efforts of the country to collect such basic data would be continued in the future if the sufficient financial and technical supports were available. The plots established for this study could be used for such measurements.

5.1.2 Pilot study in Thailand

The characteristics and ability of the semiconductor sensor technique that was used for the estimation of methane flux from rice fields were well examined under this study. Moreover, the project collaborator from Thailand acquired basic knowledge and skills to maintain and operate the sensor to conduct measurements. Therefore, the application of the sensor technique in other fields and in other countries could be implemented if the appropriate design of experiments is prepared. One of the project collaborators, Dr. Sirintornthep Towprayoon at KMUTTT, has applied for the CAPaBLE funds in response to the call for proposal in 2005, to implement the study applying this technique as one of the tools for measurements of GHG emissions in neighbouring countries in Asia (her applied project title: *Greenhouse Gas (GHG) and Aerosol Emissions under Different Vegetation Land Use in the Mekong River Basin Sub-Region*).

The study also revealed the potential of the Laser Gas Detector method for the measurement of methane flux from landfills. Further investigation should be implemented to check and confirm the ability of this method including the accuracy of the detector in terms of measurement of the absolute level of methane concentration in the air, the impacts of conditions of accessaries, such as chambers and reflectance plates, on the measurement accuracy.

5.2 Transmission of information

The results of the pilot studies were shared in regional workshops regularly. Yet, efforts to distribute the outcomes of these studies, including the developed country-specific emission removal factors, have to be emphasized more in the future at the regional and international levels so that other nations could learn from those outcomes. The project proponents and collaborators both voluntarily agreed to make a comprehensive report of this three-year project with particular attention to capturing the technical features of the project after the end of the project period. The report will be accessible to outsiders and is expected to be completed in fall in 2006.

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Appendices:

Glossary of Terms

List of abbreviations:

APN	Asia-Pacific Network for Global Change Research
CCEAP	Cambodia Climate Change Enabling Activity Project
CH4	Methane
CO2	Carbon Dioxide
DAS	Days After Seed Sowing
DoFW	Department of Forestry and Wildlife
GC	Gas Chromatograph
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
KMUTT	King Mongkut's University of Technology Thonburi
LULUCF	Land Use, Land-Use Change, and Forestry
MoEC	Ministry of Environment of Cambodia
NC	National Communication
NIES	National Institute for Environmental Studies
ppb	Part Per Billion
ppm	Part Per Million
ppbv	Part Per Billion by Volume
ppmv	Part Per Million by Volume
R^2	Regression
UNFCCC	United Nations Framework on Climate Change
WGIA	Workshop on Greenhouse Gas Inventories in Asia Region
SD	Standard Deviation
SnO_2	Tin Oxide
Pd	Palladium
Pt	Platinum

Appendix: Forest measurement methodology for the Pilot study in Cambodia

The methodology of the field survey is based on Hairiah K. et al. (2001)[2].

Aboveground biomass:

Measurement of aboveground biomass consists of two parts: one is the non-destructive sampling for the trees, including living tress and necromass, and the other is destructive sampling for the litter and undergrowth layer. The below table summarizes the overview of proposed methodology.

Table 1. Overview of the methodology

Parameters		Methodology	Plot size[*1]
1. Living trees	Larger than 30 cm diameter	Non-destructive measurement of diameter, apply allometric equation	20*100 m (Plot A)
	Larger than 5 cm and smaller than 30 cm diameter	Non-destructive measurement of diameter, apply allometric equation	5*40 m (Plot B)
2. Necromass	All dead trees that have diameter greater than 5 cm and a length of > 0.5 m	Non-destructive measurement of diameter, apply allometric equation	5*40 m (Plot B)
3. Understorey	Trees smaller than 5 cm	Destructive sampling	1*1 m and 0.5*0.5 m (Plot C)
4. Litter	Coarse and fine litters	Destructive sampling	1*1 m and 0.5*0.5 m (Plot C)

*1: To avoid borders of the plot, it is recommended to select Plot A within a plot of at least 1 ha. Plot B is set up within a Plot A and Plot C is set up in a Plot B.

Living trees:

Equipment: Line for center of transect, 100 m long for Plot A and 40 m long for Plot B, stick to measure width, 2.5 m long for Plot B, wooden sticks of 1.3 m length (for measurement of DBH), knife, measurement tape for measuring diameter which include the factor π and Hagameter or Sunnto or Vertic-III for tree height measurement.

Procedure: Set out Plot B, by running a 40 m line through the area and then sampling the trees larger than 5cm and smaller than 30cm diameter that are within 2.5m of each side of the line, by checking the distance to the central of the line (Figure 1). For each tree, tree specie is recorded and the diameter is measured at 1.3m above the soil surface (called, diameter at breast height, DBH), except where trunk irregularities at that height occur or trees branch occur below the height measurement (1.3m). For the first case, height of measurement should be higher and all branches with diameter >5cm are measured and then calculate the equivalent diameter as SQRT(ΣD^2). For the second case, just measured all branches with diameter >5cm at the measurement height (1.3m) and then calculate the equivalent diameter as SQRT(ΣD^2). Height of ten trees, selected within a plot, is measured as samples.

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[2] Hairiah K., Sitompul, SM., Van Noordwijk, M., and Palm, C. (2001). Methods for sampling carbon stocks above and below ground. Available at http://www.worldagroforestry.org/sea/Products/Training/Materials/lecture%20notes/ASB-LecNotes/ASBLecNote%204B.pdf.

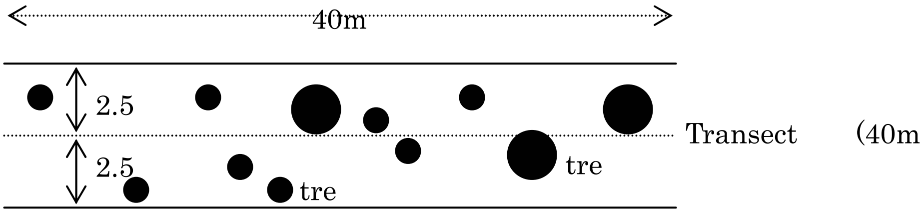

Figure 1. Plot B for measuring living trees larger than 5 cm and smaller than 30 cm

Calculation: Apply allometric equation based on the measured diameter of trees sampled.

Tree necromass:

Procedure: Within Plot B, all trunk (unburned part), dead standing trees, dead trees on the ground and stumps are sampled that have a diameter >5 cm and a length of >0.5 m. Their height (length) is recorded within the 5 m wide transect (see Figure 2) and diameter, as well as the type of wood for estimating specific density.

Calculation: For the **branched** structures, an allometric equation is used, as for living trees. For **unbranched** cylindrical structures, an equation is based on cylindrical volume, i.e. Biomass (kg) = $\pi D^2 hs/40$, where D is diameter (cm), h length (m) and s specific gravity (g cm^{-3}) of wood. The latter is estimated as 0.5 g cm^{-3} as default value, but it can be around 0.8 for dense hardwood, around 0.3 for very light species, and generally decreases during decomposition of dead wood laying on the soil surface.

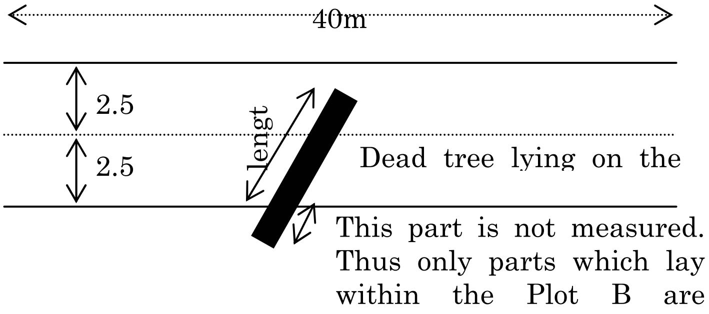

Figure 2. Plot B for measuring tree necromass

Litter and understorey

Equipment: Quadrat of 1m x 1m (Plot C, see Figure 3) in the Plot B, knives and/or scissors, scales (one allowing to weight up to 10 kg with a precision of 10 g for fresh samples and one with a 0.1 g precision for sub-samples), marker pens, plastic and paper bags, sieves with a 2 mm mesh size and trays.

Procedure: Locate sampling frames within the Plot B, as indicated in Figure 3, placing it once (randomly) in each quarter of the length of the central rope.

- *Understorey Biomass.* Trees less than 5 cm DBH, i.e. seedling or saplings, are harvested within the 1m x 1m quadrat. Weight the total fresh sample (g m^{-2}), mix well and immediately take and weigh a composite fresh sub sample (~300 g), for subsequent sun-drying.

- *Litter* is samples within the same frames in two steps.

- *Coarse litter* (any tree necromass <5cm diameter and/or <50cm length, undecomposed plant materials or crop residues, all unburned leaves and branches) is collected in 0.5m x 0.5m quadrat (0.25 m^2), on a randomly chosen location within the understorey sample. All undecomposed (green and brown) materials collected to a sample handling location.
- *Fine litter* (dark litter, including all woody roots which partly decomposed) in a 0-5 cm soil layer is taken and put in the sieves with a 2 mm mesh size for removing the soil parts. All fine litters are then put on the bags (For convenience, take the top soils and put on the bags for processing elsewhere).

- *Sample handling for destructive biomass and litter samples.*
  - **Biomass**: Sun-dry the sub-sample for conversion to dry weight and for analysis of C, N, and its quality (lignin and polyphenolic concentration which influence the decomposition rate of organic materials).
  - **Coarse litter**: To minimize contamination with mineral soil, the sample should be soaked and washed in water; the floating litter is collected, sun dried and weighed, the rest is sieved on a 2 mm mesh sieve and added to the fine litter fraction.
  - **Fine litter and roots**: The litter (incl. dead roots) and (live) root material collected on the 2 mm sieve is washed and dried.

Calculation:

Total dry weight (kg/m^2) = [Total fresh weight (kg) * Subsample dry weight (g)] / [Subsample fresh weight (g) * Sample area (m^2)]

Take the average pf the 8 samples to record the understorey and litter biomass for the transect replicate.

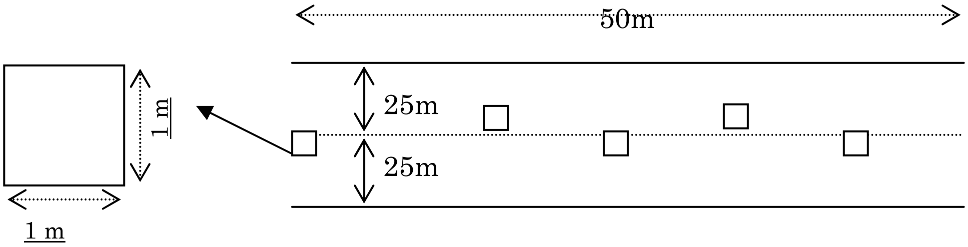

Figure 3. Plot C for measuring litter and understorey

Annual growth rate of biomass

Procedure. In Plot A and B, all trees with diameter of more than 5 cm are labelled. After 12 months (end of the year) diameter of these labelled trees are measured again. Difference in diameter between the first and second measurements indicates the diameter increment.

Calculation. Apply allometric equation for the first and second measurement, respectively and identify the difference.