Thailand's National Greenhouse Gas Inventory 1994

Ministry of Science,
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THAILAND

Thailand's National Greenhouse Gas Inventory 1994

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Advisors:
Dr. Saksit Tridech
Dr. Wanee Samphantharak
Ms. Orapin Wongchumpit
Mr. Surin Vivajsirin

Technical Co-ordinators:
Dr. Srisuda Jarayabhand
Ms. Wilailak Suraphruk

Technical Support:
Center for Applied Economic Research,
Faculty of Economics, Kasetsart University

Reviewers: Mr. Suphavit Piampongsant

Editors: Mr. Camilo Lim

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RESEARCHER

Team Leader	Asst. Prof. Dr. Vute Wangwacharakul
Energy	Asst. Prof. Dr. Pojanie Khummongkol
Agriculture and soil	Asst. Prof. Dr. Pimpan Jermsawatdipong
Livestock	Assoc. Prof. Dr. Pravee Vijchulata
Forestry	Asst. Prof. Dr. Ladawan Puangchit
Waste	Assoc. Prof. Dr.Sirintornthep Towprayoon

REVIEWERS

Energy

Dr. Supachart Chungpaibulpatana
Sirindhorn International Institute of Technology, Thamasart University
Prof. Dr.Somchart Soponronarit
Kingmongkut University of Technology Thonburi
Mr. Viraphol Jirapraditkul
National Energy Policy Office
Ms. Sirinthorn Vongsoasup
Department of Energy Development and Promotion
Dr. Prasert Sinsukprasert
Department of Energy Development and Promotion

Agriculture and soil

Dr. Pornpimol Chaiwanakupt
Department of Agriculture
Dr. Prapai Chairoj
Department of Agriculture
Dr. Chawalit Hongprayoon
Kasetsart University
Dr. Pichit Pongsakul
Department of Agriculture

Livestock

Mr. Tawatchai Indratula
Department of Livestock Development
Assoc. Prof. Dr. Somchai Chantsavang
Kasetsart University
Prof. Dr. Chanvit Vajrabukka
Kasetsart University

Forestry

Dr. Bunvong Thaiutsa
Kasetsart University
Dr. Jesada Luangjam
Royal Forest Department
Mr. Boonchoob Boontawee
Royal Forest Department
Dr. Suwit Ongsomwang
Royal Forest Department
Ms. Doojduan Sasanavin
Office of the Permanent Secretary, Ministry of Agriculture and Cooperatives

Waste

Ms. Wanna Rodratana
Department of Industrial Works
Mr. Adisak Thongkaimook
Pollution Control Department
Mr. Chungtong Opassiriwit
Bangkok Metropolitan Administration
Mr. Kitti Kumpeera
Kenan Institute Asia

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

LIST OF UNITS & ABBREVIATIONS

Prefixes and multiplication factors

Symbol	Prefix	Abbreviation	Multiplication Factor
P	peta	10^{15}	1 000 000 000 000 000
T	tera	10^{12}	1 000 000 000 000
G	giga (billion)	10^{9}	1 000 000 000
M	mega (million)	10^{6}	1 000 000
k	kilo (thousand)	10^{3}	1 000
h	hecto	10^{2}	100
da	deca	10^{1}	10
d	deci	10^{-1}	0.1
c	centi	10^{-2}	0.01
m	milli	10^{-3}	0.001
μ	micro	10^{-6}	0.000 001

Note

1 Tonne	= 10^{6} g	
1 k Tonne	= 1 Gg	
1 M Tonne	= 1 Tg	= 10^{3} Gg

Abbreviations for chemical compounds

Chemical Formula	Definition
C	Carbon
CH_4	Methane
N_2O	Nitrous Oxide
CO_2	Carbon Dioxide
CO	Carbon Monoxide
NO_x	Nitrogen Oxides
NMVOC	Non-Methane Volatile Organic Carbon
VOC	Volatile Organic Carbon

Standard Equivalents

Unit	Conversion Factors
1 tonne of oil equivalent (toe)	10.093 gcal or 42.244 GJ
1 hectare	6.25 rais
1 hectare	10,000 square meters (m^2)
1 km^2	100 ha
1 rai	1,600 square meters (m^2)
1 US dollar	25 Baht (prior to devaluation in June 1997)
	37 Baht (approximately in March 2000)
1 PJ	10^9 MJ
1 kWh of hydroelectricity	9.36 MJ

Units and Abbreviations

Unit	Symbol
Cubic meters	cu m
Cubic feet	cu ft
Degree	°
Degree celsius	°C
Dry matter	dm
Gigawatt hour	GWh
Gram	g
Hectare	ha
Hydrolic litre	HL
Joule	J
Kelvin	K
Lipda	′
Million standard cubic feet	mscf
Million tonne of oil equivalent	Mtoe
Square meters	sq m
Tonne of oil equivalent	toe
Tonne	t
Watt	W
Watt hour	Wh
Year	Yr

Acronyms and Abbreviation

BOT	Bank of Thailand
DEDP	Department of Energy Development and Promotion
DIW	Department of Industrial Works
DOC	Degradable Organic Carbon
EGAT	Electricity Generating Authority of Thailand
EMS	Environmental Management System
FIO	Forest Industry Organization
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
LPG	Liquefied Petroleum Gas
MCF	Methane Conversion Factors
MSW	Municipal Solid Waste
NESDB	National Economic and Social Development Board
OECD	Organisation for Economic Co-operation and Development
RFD	Royal Forest Department
SPP	Small Power Producer
SWDS	Solid Waste Disposal Sites
TEI	Thailand Environment Institute
TFMP	Thai Forestry Master Plan
TPC	Thai Plywood Company
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency

SUMMARY

SUMMARY

The 1994 national inventory of greenhouse gases (GHGs) represents the second official inventory of GHGs in Thailand. The first official GHG inventory for the year 1990 was prepared in 1997. The 1994 inventory is the result of the recent studies conducted by researchers from various research and academic institutes. In estimating the 1994 GHG inventory, the researchers used the 1996 IPCC Revised Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). To the extent possible, the researchers used local activity data to substitute for the default data recommended by the IPCC, thus making the latest estimates more accurate and relevant to Thailand.

Still, many gaps in knowledge exist. These suggest that continued research be undertaken to generate scientific and technical information that is suitable to local conditions and circumstances. Basic research, field observations and testing are needed to improve the quality of the data, to reduce uncertainties, and to enhance the understanding of the relationship of these emissions with productive activities in order to help determine the needs and limitations of reducing them.

1994 National GHG Emission

The national inventory of GHGs for 1994 is presented on Table I below. Gross emissions of carbon dioxide (CO_2), the main greenhouse gas, amounted to about 241 Teragrams (Tg) in 1994. Due to carbon sequestration from reforestation activities and the re-growth of natural vegetation on abandoned lands, however, net CO_2 emissions were estimated at 202 Tg.

Unlike previous GHG inventories, the amount of CO_2 emissions from forestry and land use changes has declined compared with emissions from energy activities. Energy combustion and fugitive emissions was the largest source of CO_2 emissions, accounting for about 52 percent of gross emissions of CO_2 in 1994. Industrial process also emitted a small amount of 16 Tg of CO_2 in 1994. Several factors have contributed to the slowdown in emissions from forestry and land use changes. These include the imposition of the logging ban since 1989 and increased reforestation and commercial plantation activities. At the same time, the reforestation and plantation activities have raised the amount of carbon removals from the atmosphere.

Total CH_4 emissions in Thailand were estimated at 3,157 Gg in 1994. About 2,866 Gg or 91 percent of the emissions were from agriculture. Land use change and forestry sector activities emitted about 60 Gg of CH_4, while solid waste disposal and wastewater treatment generated about 35 Gg. Thailand also produced approximately 56 Gg of N_2O in 1994, almost all of which came from agriculture. Other minor sources were energy supply sector, land use change and forestry.

Other GHG emissions estimated for 1994 were NO_x, CO and NMVOC. The emissions were 287 Gg, 555 Gg and 2,513 Gg, respectively. The energy sector was the main source of NO_x emissions (89 percent) while industrial process was almost the only source of NMVOC. Land use changes and forestry were the main CO emitters.

In terms of GWP, in 1994, Thailand emitted GHGs approximately 286 Tg of CO_2 equivalent. CO_2 contributed more than 71 percent while CH_4 emitted about 23 percent and N_2O constituted about 6 percent of the total. The amount was marginal, compared to the World total (Table II).

Energy Sector

The energy sector was the largest source of CO_2 emissions in Thailand in 1994, accounting for more than half of total national CO_2 emissions. It was also the largest source of CO and NO_x and the main source of fugitive CH_4 emissions.

Combustion of fuels was the main CO_2 emitter in energy sector accounted to 125,483 Gg in 1994. As the largest consumer of fuel, the energy supply sector (mainly power plants) emitted the largest share of CO_2 (36 percent), followed by the transport sector (32 percent) and the industry and construction sector (25 percent). When combined, these three sectors emitted more than 90 percent of CO_2 emissions and at least 97 percent of NO_x.

There were also GHGs emitted from coal mining and oil and natural gas drilling as well as from various transmission, storage and distribution systems. CO_2 and gases that have low molecular weights such as CH_4 and volatile organic carbon (VOC) are released during the process of mining, extraction and other post-mining activities, but only CH_4 emissions are estimated in this report. Nonetheless, the estimates suffer from the lack of reliable emission factors that take into consideration the stratum and depth of deposits and the quality and characteristics of the fuels.

Table I Thailand's National Greenhouse Gas Inventory, 1994 (Gg)

Greenhouse Gas Source and Sink Categories	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC
Total Emissions & Removals	**241,030.55**	**-39,101.60**	**3,171.35**	**55.86**	**286.65**	**555.11**	**2,513.30**
1. Energy	125,482.80	0.00	196.55	0.83	271.85	33.90	0.72
A. Fuel Combustion	125,482.80	0.00	2.85	0.83	271.85	33.90	0.72
Energy & Transformation Ind.	45,529.30		2.07	0.10	155.30	14.70	0.00
Industry, Mining & Construction	30,824.20		0.61	0.58	113.90	17.10	0.00
Transport	39,920.40		0.09	0.00	0.26	1.30	0.70
Commercial	890.50		0.02	0.08	0.87	0.20	0.00
Residential	3,469.40		0.06	0.06	1.37	0.50	0.00
Agriculture	4,849.00		0.00	0.01	0.15	0.10	0.02
B. Fugitive Emissions			193.7				
Solid Fuels			16.02				
Oil and Natural Gas			177.68				
2. Industrial Processes	15,970.40		0.31				2,512.58
3. Agriculture			2,879.10	54.62			
A. Enteric Fermentation			629.53				
B. Manure Management			139.64	19.19			
C. Rice Cultivation			2,110.53				
D. Agricultural Soils				35.43			
E. Prescribed Burning of Savannas							
F. Field Burning of Agri. Residues							
G. Others							
4. Land Use Change & Forestry	99,577.35	-39,101.60	59.57	0.41	14.80	521.21	
A. Changes in Forest & Other Woody Biomass Stocks	40,180.51	-39,101.60					
B. Forest & Grassland Conversion	59,396.84		59.57	0.41	14.8	521.21	
C. Abandonment of Managed Land							
D. Others							
5. Wastes			35.22				
A. Solid Waste Disposal			19.57				
B. Wastewater Treatment			15.65				

Table II Emissions of the Three Main Greenhouse Gases of Thailand, 1994

	Emissions (Gg) (A)	GWP (B)	CO_2 equivalent (C) = (A) x (B)	Percentage of Total Emission
CO_2	202,458.05	1	202,458	70.69
CH_4	3,171.35	21	66,598	23.25
N_2O	55.86	310	17,317	6.06
Total			**286,373**	**100.00**

Methane emissions from coal mining as well as oil and gas production activities were estimated at around 194 Gg in 1994. The bulk of fugitive CH_4 emissions (91 percent) came from natural gas production activities, which included extraction, processing, transport, distribution, venting and flaring. The production of 17 million tonnes of coal from surface mining leaked some 16 Gg of CH_4 into the atmosphere, while oil production, refining and storage activities produced 0.9 Gg of fugitive CH_4 emissions.

Industrial Process

Industrial production process also emitted GHGs. The most significant GHG emission from industrial process is CO_2. Industries covered in the 1994 inventory of Thailand were cement production, lime manufacturing, glass production, pulping process, iron and steel production, other chemical production, food and drink, bread production and fermentation processes.

Cement production was the largest contributor of CO_2 from industrial process by emitting nearly 15 Tg or about 93 percent, followed by lime production (6 percent). The remaining industrial process produced marginal amount of CO_2. Industrial process was almost the only source of NMVOC emission by releasing about 2.519 Tg out of the total of 2.52 Tg. Of the industrial process, whisky production alone produced about 2.48 Tg of NMVOC, followed by beer, wine and glass production. Ethylene was the only source of CH_4 which was marginal (0.3 Gg).

Agriculture

Rice and Agricultural Soil

Despite being one of the major rice producing countries in the world, Thailand's contribution to global CH_4 emissions is relatively small. Methane emissions from paddy fields were estimated at 2,110 Gg in 1994. About 86 percent of these was emitted from the cultivation of major rice, while the rest came from second rice. The reason is that only irrigated land could produce second rice, and only about a third of total irrigated land were planted to second rice in 1994.

Total emissions of N_2O from agricultural soils were estimated at 35 Gg in 1994. Of this amount, 41 percent came from direct sources through the incorporation of synthetic nitrogen fertilizer, animal manure and crop residues into the soil. About 30 percent of N_2O emissions were from indirect sources through their formation in leached/runoff water and fertilized soils. The rest of the emissions came from animal waste excreted in pasture.

The emissions of N_2O depend mainly on the amount of synthetic or chemical nitrogen fertilizers used in agricultural soils as well as on the organic fertilizers such as animal manure and crop residues that are applied to the soils. They are emitted through the fractions volatilized directly from cultivated soils and from the indirect formation of N_2O from leached or contaminated groundwater. Several other factors influence the amount of N_2O emissions as well. They include climate conditions, cultivation practices, soil and water management, and crop type.

Livestock

The two main sources of GHGs from livestock production are enteric fermentation and manure management. Methane gas is produced from enteric fermentation and from animal feces, while N_2O is produced from the management of animal manure.

Enteric fermentation is a process of digestion in herbivores or plant-eating animals, which produces methane as a by-product. Both ruminant livestock (e.g., cattle and buffalo) and some non-ruminants (e.g., pigs and horses) produce methane, but ruminants are the largest source. The amount of methane produced, however, depends upon various factors, including animal species and body size as well as the quantity and quality of feed digested.

Methane and nitrous oxide are produced from anaerobic decomposition of manure. These conditions often occur when a large number of animals are managed in a confined area such as dairy farms, beef feedlots or pig and poultry farms.

Methane emissions from enteric fermentation in livestock were estimated at 630 Gg in 1994. The largest source of enteric methane among ruminants was non-dairy cattle, followed by buffalo, dairy cattle, goat and sheep. Swine, which had a larger population than non-dairy cattle, emitted only about 13 Gg of enteric CH_4. Fecal CH_4 emissions amounted to around 139 Gg in 1994, while N_2O emissions from various manure management systems was estimated at 19 Gg. The largest source of fecal CH_4 was swine, which accounted for 87 percent of total CH_4 emitted from manure management.

Forests and Land Use

Forests act both as a source and a store (or sink) for CO_2. CO_2 is produced when forested land is converted into other land uses such as for agriculture and settlement, while CO_2 is stored when trees absorb CO_2 from the atmosphere through the process of photosynthesis. The amounts of CO_2 emitted and sequestered from forests are very difficult to estimate because of complex biological factors and the lack of reliable data, especially with regard to the rate of land use changes, the use of converted forest land, and the biomass density of forests.

Total CO_2 emitted from Thai forests was 99,577 Gg in 1994, while total CO_2 sequestered was estimated at 39,102 Gg, resulting in net CO_2 emissions of about 60,475 Gg (see Table I). The consumption of wood as fuel accounted for about 41 percent of total CO_2 emissions. The rest of the CO_2 emissions came from the off-site and on-site burning of biomass.

Wastes

The disposal of wastes and the processes employed to treat these wastes give rise to greenhouse gases, the most significant of which is methane. The two main sources of CH_4 emissions in Thailand are land disposal of waste (both landfill and open dumping methods) and the treatment of wastewaters from the domestic and industrial sectors. Although landfill is the most common disposal system for solid waste in other countries, data for Thailand in 1994 indicates that less than a quarter of wastes were disposed using this method. About 40 percent of solid wastes ended up being burned, while 30 percent were dumped in trenches or open sites. Moreover, out of the 137 solid wastes disposal systems throughout the country (excluding Bangkok), only 22 were landfills.

Estimates of the amount of CH_4 emissions from wastes amounted to 35 Gg in 1994 (see Table I). Of these, about 20 Gg were emitted from solid waste disposal. CH_4 emissions from landfill sites were estimated at 8 Gg or 43 percent of the total.

Meanwhile, about 16 Gg of CH_4 were emitted from wastewater treatment. Of these, almost 90 percent came from industrial wastewater treatment facilities. Methane emissions from domestic wastewater handling came mostly from sludge handling.

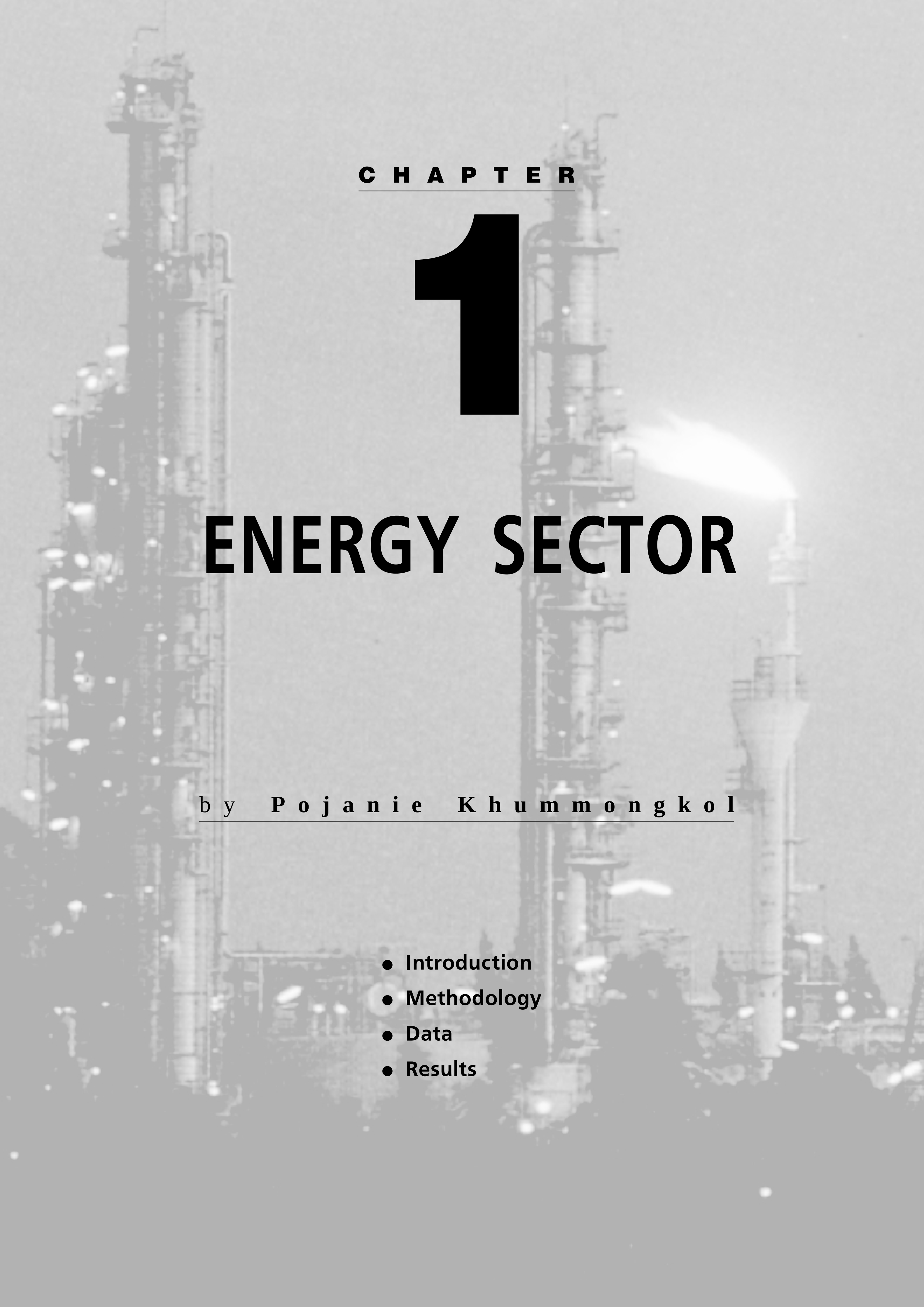
Limitations

Despite the use of local values for emission factors, cropping periods and harvesting area, the uncertainty of these estimates is still high. This is mainly due to the extreme spatial and temporal variability of methane fluxes throughout the cropping season, soil characteristics, water and crop management practices, organic matter amendments, and fertilizer application. Actual measurements of methane emissions conducted in four provinces throughout Thailand indicate a wide divergence in results. For example, methane emissions from paddy fields without fertilizer application vary from 7.49 Gg/sq m to 35.23 Gg/sq m. Field measurements also showed that the addition of organic matter to rice paddies with chemical fertilizer further increased methane emissions by as much as 135 percent compared to those without organic fertilization.

Mitigation Options

In addition to estimating the amounts of GHGs emitted, many researchers examined possible mitigation measures to reduce GHG emissions. Some were able to quantify the potentials for GHG emissions reduction, while others were limited only to identifying mitigation options and did not estimate how much could be reduced by each measure. In several cases, the suggested mitigation measures were based on studies conducted elsewhere. Hence, their suitability, acceptability and effectiveness to local conditions have yet to be proven.

The potential mitigation options identified ranged from the generation of electricity from landfills to the chemical treatment of feeds for ruminants. Some were technology based, while others, like the shift from the transplanting of rice seedlings to the direct seeding method in rice cultivation, involved a change in cultural practices. Some estimates showed that GHG emissions could be reduced by as much as 70-80 percent. The potential for reduction was even much larger when the options were combined. In the rice cultivation sector, for instance, improved water management and the use of pre-fermented organic matter instead of green manure could reduce total methane emissions by up to 30 percent.



CHAPTER

1

ENERGY SECTOR

by Pojanie Khummongkol

- Introduction
- Methodology
- Data
- Results

1.1 INTRODUCTION

Overview of Energy Sector Emissions

Greenhouse gases produced by the anthropogenic activities consist of direct GHGs, namely, CO_2, CH_4, N_2O, PFCs, HPCs, HFCs, and SF_6, as well as indirect GHGs, namely, CO, NO_x, and NMVOC. For the non-Annex I countries, which include Thailand, the GHG inventory reporting requirements are only for CO_2, CH_4, N_2O, CO, NO_x, and NMVOC.

GHG emission inventory for energy sector in this report covers emissions from all energy combustion and production activities for the base year 1994, as required by the United Nations Framework Convention on Climate Change (UNFCCC). Energy combustion activities include the consumption and conversion of fossil fuels in the energy transformation, industry, transportation, commercial, residential and agricultural sectors. Emissions of GHGs from biomass fuel use are reported, but are not included in the overall GHG emissions. For the burning of biomass fuels, the IPCC methodology requires that net CO_2 emissions be treated as zero in the energy sector. Some biomass fuels are sustainably produced, in which case the actual net emissions are zero (IPCC, 1997).

GHG emissions resulting from energy production activities come from the fugitive emissions of volatile organic carbons (VOCs) and methane. These fugitive emissions come from solid fuel production through coal mining, liquid and gaseous fuel extraction and refinery, transmission, distribution and storage.

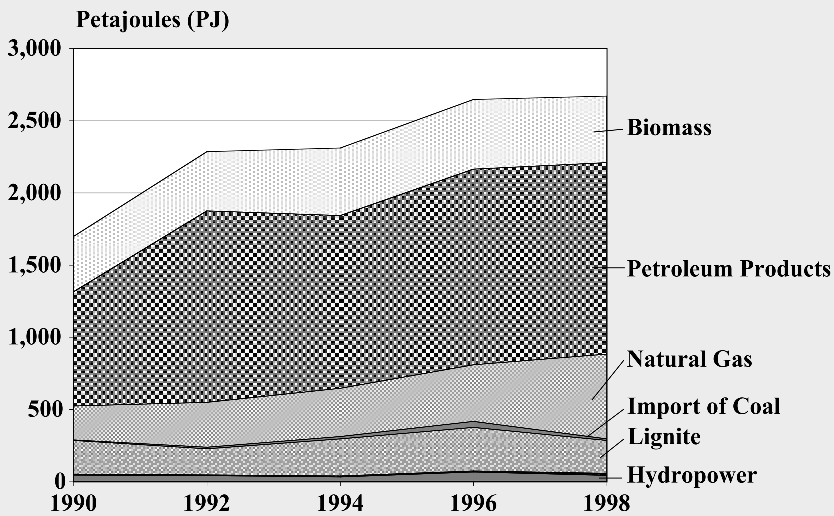
To estimate the quantity of GHG emissions from the energy sector, it is important to understand the country's energy profile, which include statistical data on the fuel mix used, sectoral demand patterns, and combustion technology employed.

Energy Profile

Total primary energy consumption in Thailand increased from 1,750 petajoules (PJ) in 1990 to over 2,600 PJ in 1998. The growth rates of energy use were in a range of 1-13 percent during the period, with the slowest growth recorded in 1992. Of the total energy utilized, about 56 percent was imported while 44 percent came from domestic production sources.

In 1994, the base year for the GHG inventory, total primary energy consumption was 2,332 PJ. Approximately 79 percent were from fossil energy sources and the rest was in the form of renewable energy. The main fossil fuels used were oil, natural gas and lignite. The composition of fossil fuels in 1994 was as follows: liquid fuel, 1,195 PJ (65 percent); solid fuel, 301 PJ (16 percent); and gaseous fuel, 335 PJ (19 percent). The breakdown of renewable energy was as follows: hydroelectricity, 3,431 GWh or 32 PJ (6 percent); wood, 165 PJ (33 percent); charcoal, 179 PJ (36 percent); and agricultural residue, 125 PJ (25 percent) (DEDP, 1998). Figure 1.1 shows the trend of energy consumption during 1990-1998.

Figure 1.1 Consumption of Primary Energy in Thailand, by Source, 1990-1998



Fossil Fuel Consumption

This section reviews the sources of fossil fuel consumption in the country. They include natural gas, petroleum products, lignite and imported coal.

- **Natural Gas**

Natural gas consumption was 9,159 million cu m (330 PJ) in 1994. Approximately 305 PJ (92 percent) were used to generate electricity, while 25 PJ (8 percent) were consumed in the industrial sector.

- **Petroleum Products**

In 1994, total petroleum products consumption was 32,466 million liters (1,194 PJ). Imported petroleum products were 9,815 million liters in the same year. Refinery output from the four domestic refineries was 491,700 barrels per day (78 million liters per day). The addition of two new oil refineries in 1996, however, has increased production capacities at present to 767,500 barrels per day (122 million liters per day). Petroleum products account for 53 percent of the total final energy consumed.

- **Lignite/Coal**

There are various lignite resources scattered around Thailand. The total proven reserves is estimated at about 2,312 million tonnes. In 1994, lignite consumption was 12 million tonnes (127 PJ), most of which were used by the power generating plants. The sub-bituminous coal produced in the country amounted to about 5 million tonnes (130 PJ) and were used mostly in the cement and tobacco-curing industries (DEDP, 1995). The tobacco-curing industry utilized a small amount of lignite (0.062 million tonnes or 0.6 PJ) in the same year.

Coal of bituminous grade were imported. In 1994, some 1.5 million tonnes (40 PJ) were imported for use mainly in the cement and pulp and paper industries.

Renewable Energy Consumption

The two most important sources of renewable energy are hydro-electricity and biomass. Other forms of renewable energy such as solar, wind and photovoltaic have not been utilized extensively in the country.

- **Hydro-electricity**

The hydroelectric potential in Thailand is estimated at about 37,010 megawatts (MW), of which 15,155 MW are within the domestic boundaries of Thailand and 21,855 MW are from international projects with neighboring countries (DEDP, 1998). In 1994, only 3,873 MW of hydropower capacity or 26 percent of the total domestic potential were utilized. Of this amount, 2,873 MW were in operation, while 1,000 MW was under construction and/or committed for implementation.

- **Solar**

The average solar radiation in Thailand is about 17 MJ per sq m per day. As the diffused component accounts for approximately 50 percent of the total radiation, solar concentrators which collect only direct radiation are hardly economical. Although non-commercial uses of solar thermal energy have been well recognized for salt production and for drying of paddy, fruits and vegetables, large-scale drying of agricultural products has been implemented with limited success owing to high capital costs. Solar thermal energy is now commercially used for water heating, with about 5,000 sq m of collectors installed per year (Soponronnarit, 1997).

- **Photovoltaic**

Photovoltaic systems have been installed mainly for lighting, water pumping and telecommunications in rural areas. More than 2 MW of photovoltaic systems have been installed in the country, with an estimated annual growth of about 50 kW per year (Kirtikara, 1993).

- **Wind**

The potential for wind energy in Thailand is rather low. The average wind speed in the country is only about 2.5 m/s. However, several locations on the southern coast and the gulf area have average wind speeds over 4 m/s, which are suitable for energy conversion. Windmills have traditionally been used in salt farms and rice fields in these areas. Wind electric power systems with a total generating capacity of 22 kW have been installed for demonstration purposes (Jivacate, 1994).

- **Biomass**

Biomass have been the main indigenous source of energy for the country. In 1994, the total supply of biomass, which included fuel wood, paddy husk and bagasse, amounted to 468 PJ and accounted for 27 percent of the country's total energy supply (DEDP, 1995).

- **Bagasse**

The sugar industry is one of the largest energy consuming industries in Thailand. In 1996, over fifty sugar mills obtained their requirements for power and process heat from 17.6 million tonnes of bagasse, which accounted for about 4 percent of the total energy supply for the country (Wibulswas and Khummongkok, 1998). The same study estimated the total power generating capacity in Thai sugar mills at 850 MW, equivalent to about 5 percent of the total power generating capacity of the country in 1996.

- **Paddy Husk**

Paddy husk is used as fuel in rice mills, brick making, cooking stoves, and others. In 1994, the supply of paddy husk was about 1.3 million tonnes, representing 1 percent of the total energy supply of the country. Another 3 million tonnes of paddy husk were not utilized as fuel and were simply burned in rice mills. Among the more than 46,000 rice mills all over Thailand, 312 are large rice mills with capacities greater than 100 tonnes of paddy per day, 52 are parboiled rice mills, and 260 are white rice mills (Ekasilp, 1996). Most of the parboiled rice mills generate power for milling and heat for parboiling.

- ***Fuel Wood from Fast Growing Trees***

The commercial plantation of fast-growing trees such as eucalyptus and acacia can partly alleviate the adverse environmental impacts posed by deforestation due to fuel wood use and the construction of large hydropower plants. It can also help reduce carbon dioxide and sulfur dioxide emissions from combustion of fossil fuels.

Large plantations of *Eucalyptus camaldulensis* can be found in the eastern region of Thailand. A survey conducted by the Forestry Research Center in 1996 showed that the total area of *Eucalyptus camaldulensis* plantations in the eastern region was 119,271 ha or 34 percent of the total Eucalyptus plantation area of the country (Hoamuangkaew, 1997). Approximately 66 percent of the total private plantations were owned by the farmers; the rest belonged to the chip wood and wood pulp industry owners.

Energy Production

The total domestic production capacity of fossil energy in 1994 was 620 PJ. They included 10,727 million cu m (386 PJ) of natural gas, 9.7 million barrels (56 PJ) of crude oil, and 17 million tonnes (178 PJ) of lignite. Natural gas accounted for 62 percent, crude oil 9 percent, and lignite 29 percent of the total energy produced in the country. Figure 1.2 shows the energy production capacity of Thailand during 1994-1997.

Energy Imports

Thailand imported a total of 1,189 PJ of energy in 1994 (DEDP, 1995). The imported energy consisted of coal, crude oil, petroleum products, and hydro-electricity. Total imports of crude oil was 21,639 million liters (786 PJ), accounting for 66 percent of the total energy imported. In addition, a total of 9,759 million liters (361 PJ) of petroleum products was imported, accounting for 30 percent. The imported petroleum products consisted of gasoline (26 PJ), jet fuel (18 PJ), diesel (174 PJ), fuel oil (140 PJ), and LPG (3 PJ).

Coal imports amounted to 1.4 million tonnes (37 PJ) or about 3 percent of the total solid fuels utilized in 1994. They were used mostly in the cement and pulp and paper industries.

Thailand also purchased hydro-electricity from its neighbors equivalent to 3 PJ of primary energy (EGAT, 1998). This amount accounted for less than 1 percent of the total energy imported.

Figure 1.3 shows the different types of energy imported by Thailand in 1994. The chart also shows the various types of petroleum products imported into the country.

Figure 1.2 Energy Production, 1994-1997

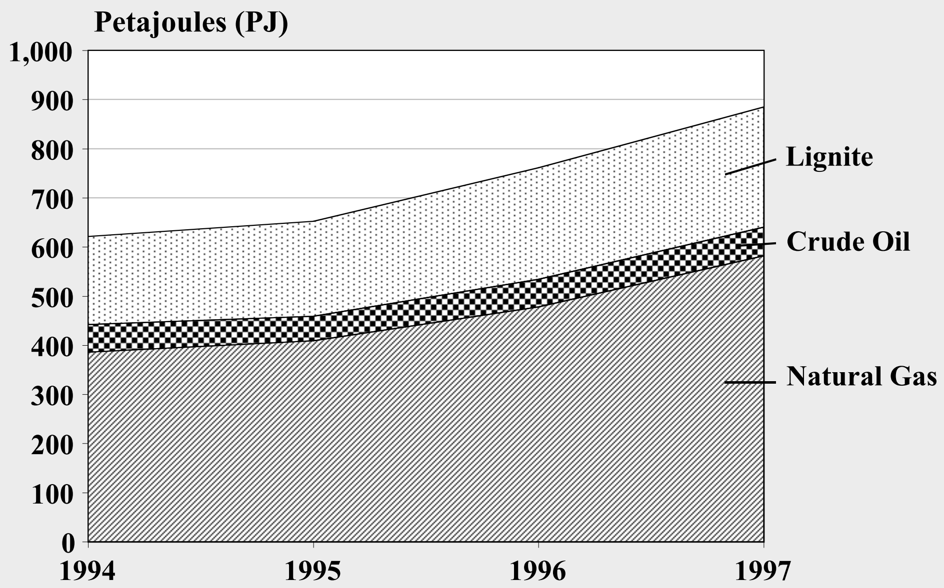
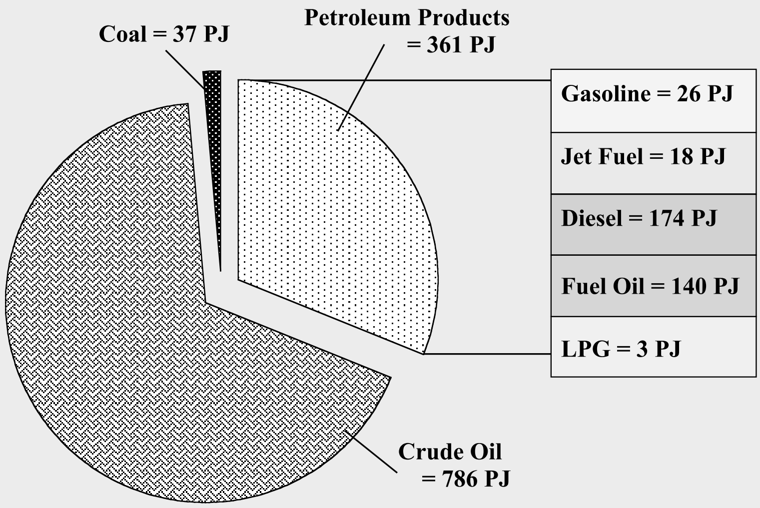


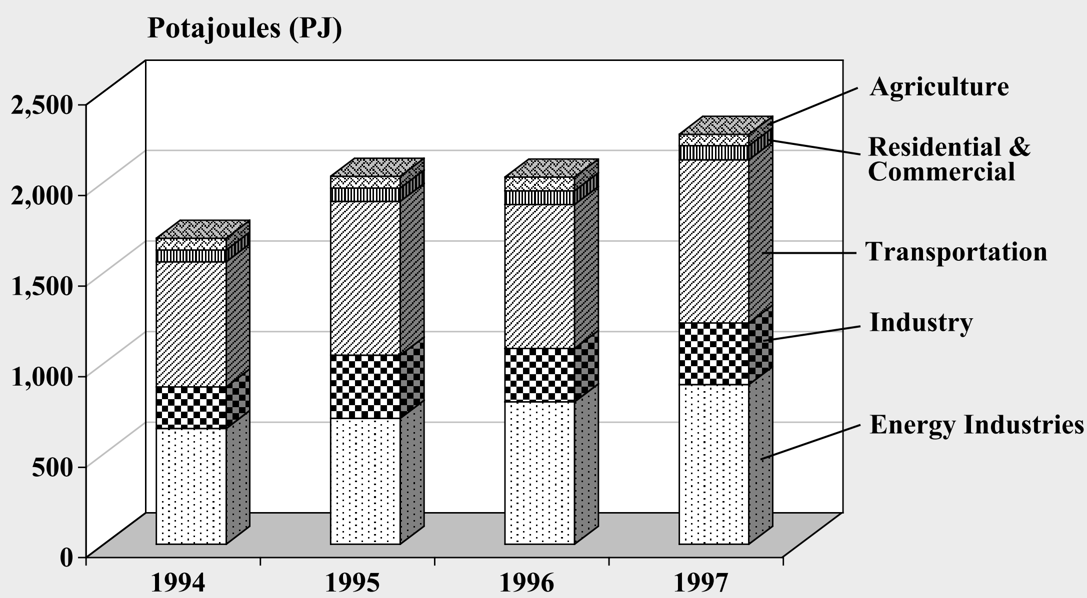
Figure 1.3 Energy Imports, by type of fuel, 1994



Sectoral Analysis and Trends

More than 95 percent of the 1,735 PJ of final energy consumed in 1994 were used in 3 sectors, namely, energy industries, transportation, and industry and construction. In 1994, the energy industries sector consumed 640 PJ or 37 percent of total energy consumption. Meanwhile, the transportation sector accounted for 557 PJ or 32 percent, while the industry and construction sector consumed 374 PJ or 22 percent. The combined energy consumption in the commercial, residential and agricultural sectors was 135 PJ or 8 percent of the total energy used in the same year. Energy transformation and other losses accounted for 29 PJ or 1 percent. Figure 1.4 shows the sectoral classification of energy consumption during 1994-1997.

Figure 1.4 Fossil Energy Consumption, classified by economic sectors, 1994-1997



1.2 METHODOLOGY

The IPCC methodology was used to estimate GHG emissions from fossil fuel combustion activities. The IPCC methodology is based on the carbon content of each type of fuel, expressed in terms of the amount of carbon per unit of energy contained in the fuel (the emission factor), and the quantity of fuel used in the economy. Details of the calculation for the combustion activity category are compiled in the IPCC Standard Worksheets 1-1 to 1-3. For emissions of GHGs from energy production activities, the details of calculation are shown in the IPCC Standard Worksheets 1-6 and 1-7.

The CO_2 emissions are reported by source categories, i.e., by fuel types and in each of the six economical sectors, namely, energy industries, transportation, industry and construction, commercial, residential, and agriculture. Bunker fuels are fuels used for international or cross-boundary transportation, such as ocean-going vessels and international aircraft. The amount of the bunker fuel consumption is not included in the national GHG emission inventory. However, for information purposes, the quantities and types of fuels delivered for international marine and aviation bunkers and their corresponding emissions are reported separately.

Non-CO_2 emissions, in terms of CH_4, N_2O, NO_x, CO and NMVOC gases, were also estimated for the six economic sectors. The method for calculating non-CO_2 emissions is more elaborate. For stationary sources of emissions, the amount of emissions was evaluated according to the types of technologies employed, e.g., type of furnace, emission control devices, etc. For mobile sources of emissions, however, additional parameters were required, such as statistical data on the type and quantity of energy consumed, number and vintage of vehicles in each mode of transport (i.e., road, rail, air, and water), share of fuel used, share of vehicle types, fuel efficiency, and annual distance traveled by each type of vehicle.

Estimates of CO_2 emission from biomass were reported in the context of an informative entry, since some of the biomass fuels are produced sustainably and the IPCC methodology requires that net CO_2 emissions be treated as zero in the energy sector. Moreover, all GHG emissions were reported for the year 1994, as required by the revised IPCC Guidelines as the base year for international inventory and comparison.

The IPCC Reference Approach to estimate CO_2 emissions requires the estimation of Apparent Consumption of the fossil fuels and is calculated as follows:

Apparent Fuel Consumption = **Production**
+ Imports
– Exports
– International Bunkers
– Stock Change

The apparent consumption of fuel is converted from physical to common energy units by using appropriate conversion factors. The carbon content of fuels is then evaluated from the total apparent consumption and carbon dioxide derived. All of these figures are calculated using the following equations:

Apparent Consumption (TJ) = **Apparent Consumption (Physical Units)**
x **Conversion Factor (TJ/Physical Units)**

Total Carbon Dioxide (GgC) = **[Total Carbon Content (GgC)**
– Total Carbon Stored (GgC)]
x **Fraction of Carbon Oxidized (by fuel type)**
x **44/12**

where:

Total Carbon Content (GgC) = **Σ Apparent Consumption (by fuel type in TJ)**
x **Carbon Emission Factor (by fuel type in tC/TJ)**
x **10^{-3}**

Total Carbon Stored (GgC) = **Non-Energy Use (10^3 t)**
x **Conversion Factor (TJ/10^3 t)**
x **Emission Factor (t C/TJ)**
x **Fraction of Carbon Stored**
x **10^{-3}**

In using these formulae, the first step is to determine the *Activity Data* from each sector by fuel type, combustion technology, and emission control technology, if any. The second step is to multiply the *Activity Data* of each category by the appropriate *Emission Factor* to compute potential emission. The total emission is the sum of the individual estimates across activities, technologies and fuels.

The conversion factor is the energy content of the fuel per physical unit of the fuel. It is used to convert the amount of fuel consumed from their physical quantities (e.g., kg, liter, etc.) into the standard international energy unit, terajoule (TJ). Table 1.1 shows the emission factors for each type of fuel used in the calculations.

Table 1.1 **Emission Factor to Convert Energy Consumed from Physical Units into the International Standard Energy Unit, Classified by Fuel Type**

Fuel type	Emission factor
Liquid Fuel	Liquid fuel unit: (MJ/L)
Gasoline	31.48
Jet fuel	34.53
Kerosene	34.53
Diesel oil	36.42
Fuel oil	39.77
LPG	26.62
Bitumen	41.19
Solid Fuel	Solid fuel unit: (MJ/kg)
Anthracite	31.4
Bituminous coal	26.37
Sub-bituminous coal	26.37
Lignite	10.47
Coke	27.63
Gaseous Fuel	Gaseous fuel unit: (MJ/scf)
Natural gas	1.02
Biomass	Biomass fuel unit: (MJ/kg)
Charcoal	27.38
Wood	15.99
Paddy husk	13.65
Bagasse	7.14

Souce: Department of Energy Development and Promotion (DEDP), 1995.

The carbon emission factor is the amount of carbon contained in the fuel per unit of energy. It is used to estimate CO_2 emissions. The IPCC-recommended carbon emission factors are listed on Table 1.2.

Since not all of the carbon contained in the fuel is oxidized to form carbon dioxide, the fraction of carbon that is oxidized is applied to estimate actual CO_2 emission. This study uses the IPCC-recommended fractions for carbon oxidization for coal, oil and gas of 0.98, 0.99 and 0.995, respectively. For biomass, the fraction of carbon oxidization used is 0.98.

The general equation for evaluating GHG emissions of non-CO_2 from fuel combustion activities is as follows:

$$\textbf{Emission} = \Sigma\,(\mathbf{EF_{abc}} \times \mathbf{Activity_{abc}})$$

where:

EF	=	Emission Factor (g/GJ)
Activity	=	Energy Input (GJ)
a	=	Fuel Type
b	=	Sector Activity
c	=	Technology Type

Non-CO_2 gases consist of CH_4, N_2O, NO_x, CO, and NMVOCs. The emission factors for these non- CO_2 gases are shown on Table 1.3 to Table 1.7.

Table 1.2 Carbon and Carbon Dioxide Emission Factors, by Fuel Type

Fuel type	Carbon emission factor (tonne C/TJ)
Liquid Fuel	
Gasoline	18.9
Jet fuel	19.5
Kerosene	19.5
Diesel oil	20.2
Fuel oil	21.1
LPG	17.2
Bitumen	22.0
Solid Fuel	
Anthracite	26.8
Bituminous coal	25.8
Sub-bituminous coal	25.8
Lignite	27.6
Coke	29.5
Gaseous Fuel	
Natural gas	15.3
Biomass	
Charcoal	31.5
Wood	29.9
Paddy husk	26.3
Bagasse	26.3

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2, OECD, 1997.

Table 1.3 Methane Emission Factors

Activity			CH_4 Emission factors (kg/TJ)											
			Gasoline	Aviation Fuel	Kerosene	Diesel	Fuel Oil	LPG	Anthracite	Bitnmin Coal	Sub-bitum. Coal	Lignite	Coke	Natural Gas
Energy Industries						0.03	0.7					0.6		6.1
Manufacturing Industries and Construction			0.6		0.6	0.6	2.9	1.2	1.0	1.0	1.0		1.0	1.1
Transport	Domestic Aviation			0.002										
	Road: Passenger car		0.007			0.002		0.021						
	Light duty vehicle		0.018			0.001								
	Heavy duty vehicle					0.006								0.61
	Motorcycles/Tricycles		0.115					0.021						
	Railways		0.005			0.005								
	National Navigation		0.005			0.005	N/A							
Other Sectors	Commercial				0.6	0.6	1.6	1.2						
	Residential				5			1.1						
	Agricultural/ Forestry/Fishing	Stationary			0.6		1.6	1.2						
		Mobile	0.011			0.011								

Table 1.4 Oxides of Nitrogen Emission Factors

Activity			Gasoline	Aviation Fuel	Kerosene	Diesel	Fuel Oil	LPG	Anthracite	Bitnmin Coal	Sub-bitum. Coal	Lignite	Coke	Natural Gas
			NO_x Emission factors (kg/TJ)											
Energy Industries						68	201					461		187
Manufacturing Industries and Construction			64		64	64	161	67	N/A	527.0	527.0		N/A	67
Transport	Domestic Aviation				0.29									
	Road: Passenger car		0.007	0.18			0.26		0.8					
	Light duty vehicle		0.66			0.37								
	Heavy duty vehicle					1.0								0.35
	Motorcycles/Tricycles		0.06					0.8						
	Railways		1.8			1.8								
	National Navigation		1.6			1.6	2.1							
Other Sectors	Commercial				64	64	64	48						
	Residential				N/A			47						
	Agricultural/ Forestry/Fishing	Stationary			64		64	48						
		Mobile	1.5			1.5								

Table 1.5 Nitrous Oxide Emission Factors

Activity			N_2O Emission factors (kg/TJ)											
			Gasoline	Aviation Fuel	Kerosene	Diesel	Fuel Oil	LPG	Anthracite	Bitnmin Coal	Sub-bitum. Coal	Lignite	Coke	Natural Gas
Energy Industries						N/A	N/A					0.8		N/A
Manufacturing Industries and Construction			15.7		15.7	15.7	N/A	N/A	N/A	N/A	N/A		N/A	N/A
Transport	Domestic Aviation				N/A									
	Road: Passenger car		0.007	0.002			0.004		0.000					
	Light duty vehicle		0.0009			0.004								
	Heavy duty vehicle					0.003								N/A
	Motorcycles/Tricycles		0.002					0.000						
	Railways		0.002			0.002								
	National Navigation		0.002			0.002	0.002							
Other Sectors	Commercial				15.7	15.7	15.7	2.4						
	Residential				5			1.1						
	Agricultural/	Stationary			15.7		15.7	2.4						
	Forestry/Fishing	Mobile	0.002			0.002								

Table 1.6 Carbon Monoxide Emission Factors

Activity			CO Emission factors (kg/TJ)											
			Gasoline	Aviation Fuel	Kerosene	Diesel	Fuel Oil	LPG	Anthracite	Bitnmin Coal	Sub-bitum. Coal	Lignite	Coke	Natural Gas
Energy Industries						15	15					14		32
Manufacturing Industries and Construction			16		16	16	15	17	211.0	79.0	79.0		211.0	17
Transport	Domestic Aviation				0.12									
	Road: Passenger car		0.007	1.03			0.28		2.65					
	Light duty vehicle		8.33			0.41								
	Heavy duty vehicle					0.84								0.73
	Motorcycles/Tricycles		16.8					2.65						
	Railways		0.61			0.61								
	National Navigation		0.50			0.50	0.046							
Other Sectors	Commercial				16	16	16	9.6						
	Residential				N/A			10						
	Agricultural/	Stationary			16		16	9.6						
	Forestry/Fishing	Mobile	0.6			0.6								

Table 1.7 Non-methane Volatile Organic Carbon (NMVOC) Emission Factors

Activity			Gasoline	Aviation Fuel	Kerosene	Diesel	Fuel Oil	LPG	Anthracite	Bitnmin Coal	Sub-bitum. Coal	Lignite	Coke	Natural Gas
			NMVOC Emission factors (kg/TJ)											
Energy Industries						N/A	N/A					N/A		N/A
Manufacturing Industries and Construction			N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A
Transport	Domestic Aviation				0.18									
	Road: Passenger car		0.007	1.18			0.07		0.56					
	Light duty vehicle		0.7			0.11								
	Heavy duty vehicle					0.19								0.09
	Motorcycles/Tricycles		11.77					0.56						
	Railways		0.13			0.13								
	National Navigation		0.11			0.11	N/A							
Other Sectors	Commercial				N/A	N/A	N/A	N/A						
	Residential				N/A			N/A						
	Agricultural/	Stationary			N/A		N/A	N/A						
	Forestry/Fishing	Mobile	0.23			0.23								

1.3 DATA

Energy consumption, classified by fuel type, is presented on Table 1.8. In 1994, the total consumption of fossil and biomass fuels was approximately 1,735 PJ and 468 PJ, respectively. Liquid fuels accounted for the largest share of combustion at 1,100 PJ (63 percent). Gaseous and solid fuels contributed 334 PJ (19 percent) and 301 PJ (17 percent), respectively.

Energy consumption, by sector, is shown on Table 1.9. The transportation (557 PJ) and energy industries (640 PJ) sectors used the most energy, all of which came from fossil fuels. The industry and construction sector used 374 PJ of energy from fossil fuels, while the residential, commercial and agricultural sectors consumed a combined total of 135 PJ.

Biomass fuels, which are consumed mainly in the residential and industrial sectors, accounted for 468 PJ in 1994.

Table 1.8 Energy Consumption, by Fuel Type, 1994

Type of Fuel	Production	Import	Export	Inter bunkers	Stock Change	Apparent Consump. (Phys.Unit)	Conversion Factor (MJ/unit)	Apparent Consumpt. (TJ)
Total Fossil								**1,735,121.0**
Liquid (10^6 liters)						**30,699.6**		**1,099,943.6**
Gasoline	4,713	833	-239	0	284	5,591	31.48	176,004.7
Jet Kerosene	2,701	525	-10	-2,773.4	-103	339.6	34.53	11,725.4
Kerosene	129	0	0	0	-13	116	34.53	4,005.5
Diesel Oil	8,422	4,783	-71	-137	170	13,167	36.42	479,542.1
Fuel Oil	5,817	3,524	-26	-801	-331	8,183	39.77	325,437.9
LPG	2,307	94	-27	0	75	2,449	26.62	65,192.4
Bitumen	305	56	0	0	-3	358	41.19	14,746.0
Solid ('000 tonnes)						**18,717**		**300,592.9**
Anthracite	12	1	0	0	-5	8	31.4	251.2
Bituminous Coal	0	1,416	110	0	0	1,526	26.37	40,240.6
Sub-bit. Coal	4,951	0	0	0	-26	4,925	26.37	129,872.3
Lignite	12,132	0	0	0	16	12,148	10.47	127,189.6
Coke		110				110	27.63	3,039.3
Gas (mscf)						**328,024**		**334,584.5**
Natural Gas	328,024	0	0	0	0	328,024	1.02	334,584.5
Total Biomass ('000 tonnes)								**468,365.7**
Wood	10,308	0	0	0	0	10,308	15.99	164,824.9
Charcoal	6,521	21	-10	0	0	6,532	27.38	178,846.2
Paddy Husk	1,312	0	0	0	0	1,312	13.65	17,908.8
Bagasse	14,956	0	0	0	0	14,956	7.14	106,785.8

Source: Department of Energy Development and Promotion (DEDP), 1995

Table 1.9 Energy Consumption, by Sector, 1994 (TJ)

Fuel Type	Energy Industries	Industries & Construction	Commercial	Residential	Agriculture	Transport	Total
Fossil	**640,375.3**	**374,118.1**	**13,538.5**	**55,438.1**	**66,242.6**	**557,057.2**	**1,706,769.8**
Gasoline		2,518.4			2,077.7	171,408.7	176,004.8
Jet Kerosene						11,740.2	11,740.2
Kerosene		2,348.0	656.1	971.6	34.5		4010.2
Diesel Oil	17,408.8	32,049.6	182.1		63,188.7	365,984.6	478,813.8
Fuel Oil	190,458.5	131,479.6	2,664.6		835.2		323,437.9
LPG		1,086.0	10,035.7	54,466.5	106.5	7,719.8	73,414.5
Bitumen							
Anthracite		251.2					251.2
Bituminous Coal		37,339.9					37,339.9
Sub-bit. Coal	211.0	129,661.3					129,872.3
Coke		3,039.3					3,039.3
Lignite	127,189.6						127,189.6
Natural Gas	305,107.5	24,569.8				204.0	329,881.3
Biomass		**157,512.8**		**310,674.6**			
Charcoal				178,545.0			178,545.0
Wood		32,763.5		132,061.4			164,814.9
Paddy Husk		17,963.4		68.3			18,031.7
Bagasse		106,785.8					106,785.8
Total							**468,177.4**

Source: Department of Energy Development and Promotion (DEDP), 1995

1.4 RESULTS

Carbon Dioxide Emissions

Table 1.10 summarizes the contribution to overall CO_2 emissions of each economic sector and fuel combustion source. In 1994, the use of fossil fuels in Thailand produced a total CO_2 emissions of approximately 125,483 Gg (125 million tonnes). As the largest consumer of fuel, the energy industries sector emitted the highest proportion of CO_2 (36 percent), followed by the transportation sector (32 percent). Although consuming a large quantity of electricity, the commercial sector contributed the least (0.7 percent) to overall fossil fuel-derived CO_2 emissions. The reason is that electricity is a secondary form of energy; thus, in order to avoid double-counting, CO_2 emissions from its conversion is accounted for in the energy industries sector.

If the type of fuel used were considered in the energy industries sector, natural gas would the largest source of CO_2 emissions. But this hides the fact that CO_2 emissions would be even larger if other fossil fuels, especially coal and lignite, were used instead. Natural gas has the advantage of having a lower CO_2 emission factor compared with solid and liquid fossil fuels, and the shift to this cleaner fuel has already reduced the impact of CO_2 emissions on the economy.

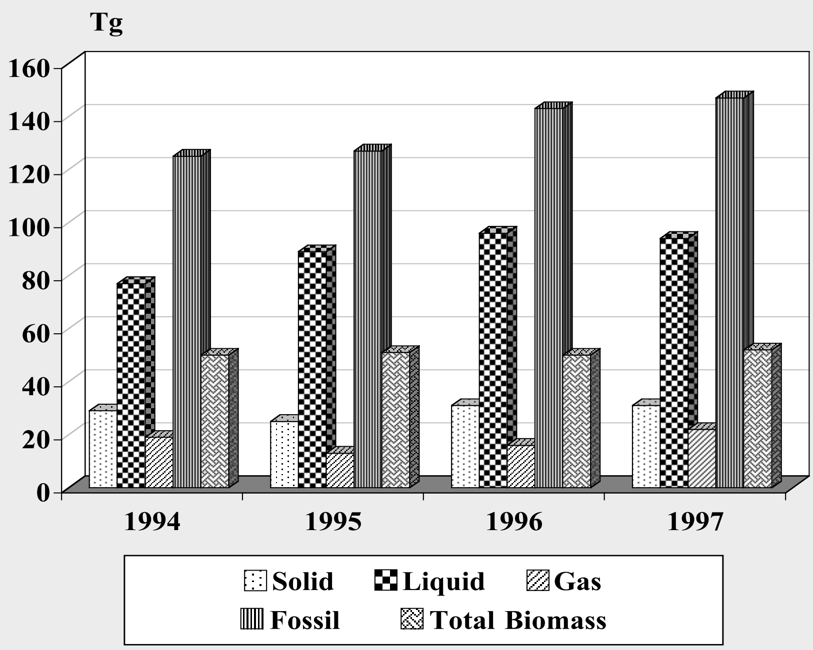
The emission of CO_2 from biomass was 49,714 Gg, with the industrial and residential sectors accounting for 15,310 Gg (31 percent) and 34,405 Gg (69 percent of total emissions), respectively.

For an overview of the trend in CO_2 emissions during the last few years, Figure 1.5 summarizes the contribution to overall CO_2 emissions of the different fuel sources during 1994-1997. The overall trend in CO_2 emissions during 1994-1997 was for CO_2 emissions to increase in all sectors. From only 125,483 Gg in 1994, the total CO_2 emission was estimated to reach 147,200 Gg in 1997.

Table 1.10 CO_2 Emissions from Fuel Combustion, by Fuel Type, 1994 (Gg)

Fuel Type	Energy Industries	Industries & Construction	Commercial	Residential	Agriculture	Transport	Total
Fossil	**45,529.3**	**30,824.2**	**890.5**	**3,469.4**	**4,849.0**	**39,920.4**	**125,482.8**
Liquid	**15,864.3**	**13,437.6**	**890.5**	**3,469.5**	**4,848.9**	**39,427.1**	**77,937.9**
Gasoline		172.8			142.5	11,759.8	12,075.1
Jet Kerosene						831.0	831.0
Kerosene		166.2	46.4	68.8	2.4		283.8
Diesel Oil	1,276.5	2,350.1	13.4		4,633.4	26,836.3	35,109.7
Fuel Oil	14,587.8	10,070.4	204.1		64.0		24,926.3
LPG		678.1	626.6	3,400.7	6.6	482.0	5,914.0
Bitumen							
Solid	**12,634.1**	**16,015.1**					**28,649.2**
Anthracite		24.2					24.2
Bituminous Coal		3,461.7					3,461.7
Sub-bit. Coal	19.9	12,207.0					12,226.9
Lignite	12,614.2						12,614.2
Coke		322.2					322.2
Gas	**17,030.9**	**1,371.5**				**11.3**	**18,413.7**
Natural Gas	17,030.9	1,371.5				11.3	18,413.7
Total Biomass		**15,309.5**		**34,404.7**			**49,714.2**
Charcoal				20,209.5			20,209.5
Wood		3,520.1		14,188.8			17,708.9
Paddy Husk		1,697.6		6.4			1,704.0
Bagasse		10,091.8					10,091.8

Figure 1.5 Carbon Dioxide Emissions, by Fuel Type, 1994-1997



The economic crisis in Thailand which started in May 1997 is expected to effect the demand for energy in all sectors. As shown on Figure 1.6, the emissions rate of CO_2 from the transportation sector as well as the industry and construction sectors appear to have declined in the aftermath of the crisis. In 1997, both sectors posted a negative rate of minus 2 percent from the previous year. Over the next several years, the economic slump is expected to continue to dampen the demand for energy and to reduce further the amount of CO_2 emissions.

Non-Carbon Dioxide Emissions

The energy industries sector, as the largest consumer of energy, accounted for much of the non-CO_2 gases emitted in Thailand in 1994 (see Table 1.11). The sector emitted 2.07 Gg of CH_4, 0.1 Gg of N_2O, 155.3 Gg of NO_x 14.7 Gg of CO, and a very small quantity of NMVOCs. Non-CO_2 emissions from other sectors are also shown on Table 1.11. It should be noted that the amounts of non-CO_2 emitted were much smaller than the CO_2 emitted by all sectors.

Figure 1.6 Carbon Dioxide Emissions, by Sector, 1994-1997

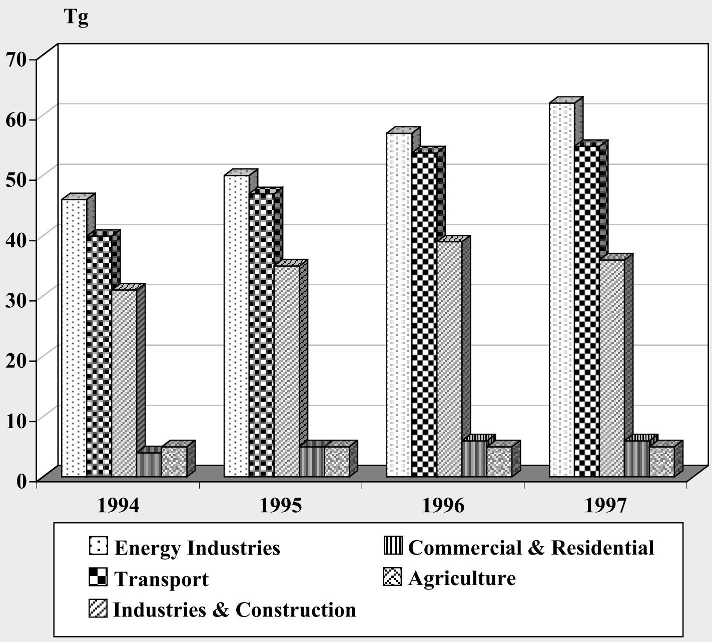


Table 1.11 Non-CO_2 Emission from Fuel Combustion, by Sector, 1994 (Gg)

Sector	CH_4	N_2O	NO_x	CO	NMVOCs
Total	2.85	0.83	271.85	33.9	0.72
Energy Industries	2.07	0.10	155.3	14.7	0.0
Industries & Construction	0.61	0.58	113.9	17.1	0.0
Transportation	0.09	0.00	0.26	1.3	0.7
Commercial	0.02	0.08	0.87	0.2	0.0
Residential	0.06	0.06	1.37	0.5	0.0
Agriculture	0.00	0.01	0.15	0.1	0.02

Figure 1.7 shows the trend of non-CO_2 emissions over the last few years. During this period, emissions of NO_x increased significantly from 272 Gg in 1994 and to 362 Gg in 1997. The emission of CO was also estimated to have grown from 34 Gg in 1994 to 43 Gg in 1997. The emission of other gases, i.e. CH_4, N_2O, and NO_x, were insignificant.

By economic sector, the largest non-CO_2 emission was from the energy industries sector (see Table 1.11). Emissions from the rest of the economic sectors were insignificant when compared to the energy industries sector. It should be noted, however, that some sectors appeared to contribute only small quantities. In certain cases, this may be due to the unavailability of default emission factors provided by the IPCC.

Fugitive Emissions

In view of the energy crises in 1972 and 1984, Thailand has increased its exploration and utilization of domestic energy resources. As a result, there has been an increase in GHGs emitted from coal mining and oil and natural gas drilling as well as from various transmission, storage and distribution systems.

GHG emissions from various energy production activities are called *'fugitive emissions'*. These gases are not related to emissions from combustion for heat utilization. Fugitive emissions occur from solid fuel energy production processes during mining, post-mining and post-combustion of coal activities. During oil and natural gas production, they occur through leakages from the extraction, storage and transmission to end users. In these processes, leakages of any gas components that have a low molecular weight, e.g., methane and volatile organic carbon (VOC), are likely to occur.

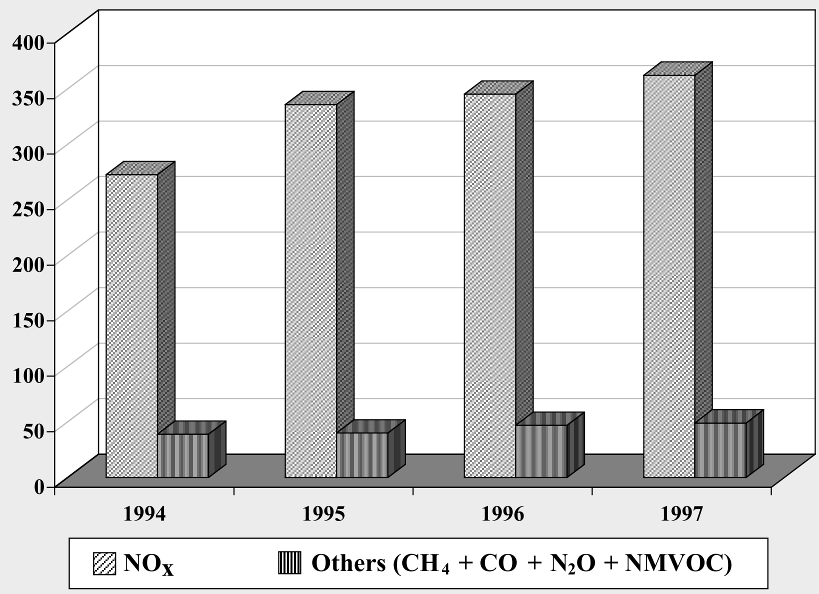
The following section outlines the types of GHGs emitted and the methodology used to estimate the extent of fugitive emissions.

By far the most significant GHG emitted during coal mining and processing activities is methane, the only GHG estimated in this study. Although some carbon dioxide is also released during the mining process, it is not evaluated here due to the lack of reliable emission factor data. Carbon dioxide emission from mining activities is highly dependent upon the stratum and depth of the coal deposits, and research to evaluate such fugitive emissions is required. Another source of carbon dioxide emission is the burning of coal deposits and waste piles.

The IPCC noted in its revised 1996 Guidelines that such burning, as reported by Marland and Rotty (1984), equates to less than the 0.3 percent of total coal produced, and 1 percent of total coal consumption in the USA. Emissions of carbon dioxide from these sources are thus not included in this study.

The IPCC suggests two possible approaches for estimating methane emission from surface mining: the Global Average and Basin Specific methods. The Basin Specific Method is more sophisticated and requires knowledge of the content of methane both in the coal being mined and in the strata below the coal seam. These are not available in Thailand. Therefore, the Global Average Method, which requires knowledge only of the quantity of coal produced annually, is used in this study to evaluate methane emission.

Figure 1.7 Emissions of Non-CO_2, 1994-1997



For coal mining activities, the methodology for calculating methane emission from surface coal mining is under Tier 1, which uses the global average emission factors. The equation used is as follows:

CH_4 Emissions (Gg) = **Coal Production (106 tonnes)**
x **Emission Factor (cu m CH_4/tonnes coal)**
x **Conversion Factor (Gg CH_4/10^6 cu m CH_4)**

where:

Conversion Factor = 0.67 Gg CH_4/10^6 m^3 CH_4 at 20ºC and 1 atm

For oil and natural gas production, the production-based average emission factors is used for estimating methane emissions. The equation is:

Fugitive Methane Emissions (Gg) = **Oil Production (PJ)**
x **Emission Factor from the specified region (kg CH_4/PJ)**
x **Conversion Factor (10^{-6} Gg CH_4/kg CH_4)**

Table 1.12 lists the emission factors for oil and natural gas production. The quantities of coal, crude oil and natural gas production activities in 1994 are shown on Table 1.13.

Methane emissions from surface coal mining, oil and gas production activities are shown on Table 1.14. In 1994, the total emission of CH_4 from the coal mining, oil and gas production was 193.7 Gg. Approximately 16 Gg, 1 Gg, and 177 Gg were emitted from coal mining, oil production and gas production activities, respectively. The largest share of fugitive emissions came from natural gas production activities, which included production, processing, transport, distribution, venting and flaring. Total fugitive emissions increased by an average of 8 percent annually during the period 1994-1997 as shown on Figure 1.8.

Table 1.12 Methane Emission Factors for Crude Oil and Natural Gas

Activities	CH_4 Emission factor (kg CH_4/PJ)
Oil:	
Production	2,480
Refining	745
Storage	140
Gas:	
Production	67,795
Processing, Transport, and Distribution	228,305
Venting and Flaring from Oil/Gas production	192,000

Source: Revised 1996 IPCC Guidelines for National GHG Inventories, Vol. 2.

Table 1.13 Coal, Oil and Natural Gas Production Activities, 1994

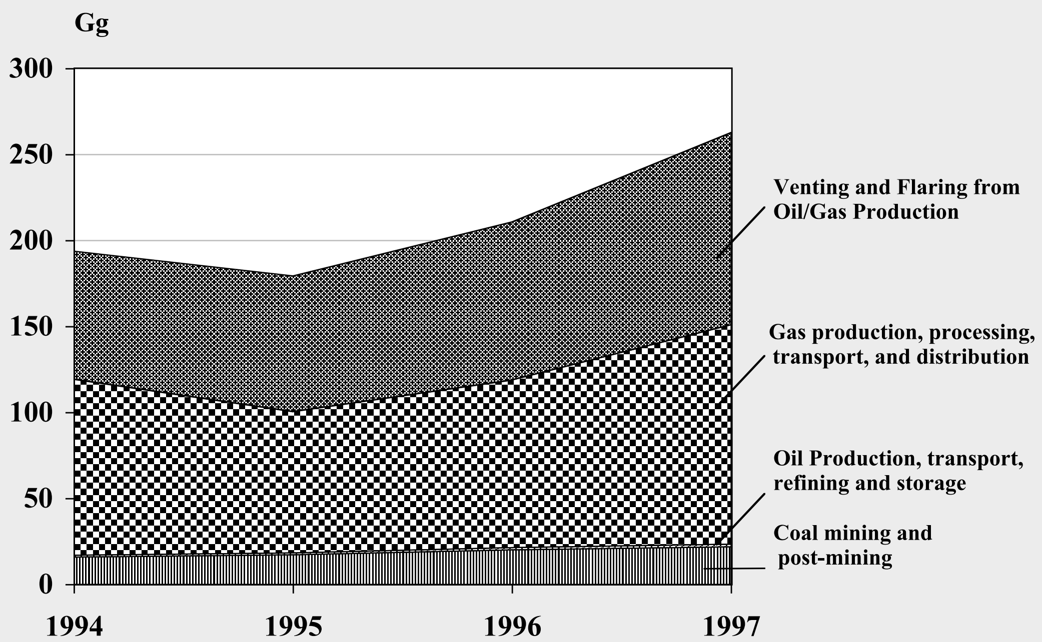
Fossil Fuel	Production	
	Amount	(Petajoules)
Coal mining (million tonnes)	17.1	178.9
Crude oil production (barrels)	9,692,210.0	56.0
Natural gas production (10^6 scf)	378,779.0	386.4

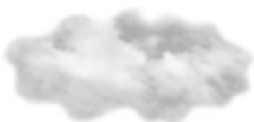
Source: National Energy Policy Office Report (1998).

Table 1.14 Methane Emissions from Fossil Fuel Production Activities, 1994

Activities	Methane (Gg)
Coal	**16.02**
Mining	14.88
Post-mining	1.14
Oil	**0.92**
Production	0.14
Refining	0.66
Storage	0.12
Natural Gas	**176.76**
Production	26.19
Processing, Transport, and Distribution	76.39
Venting and Flaring	74.18
Total Emissions	**193.70**

Figure 1.8 Fugitive Emission from Coal, Oil, and Gas Production Activities, 1994-1997





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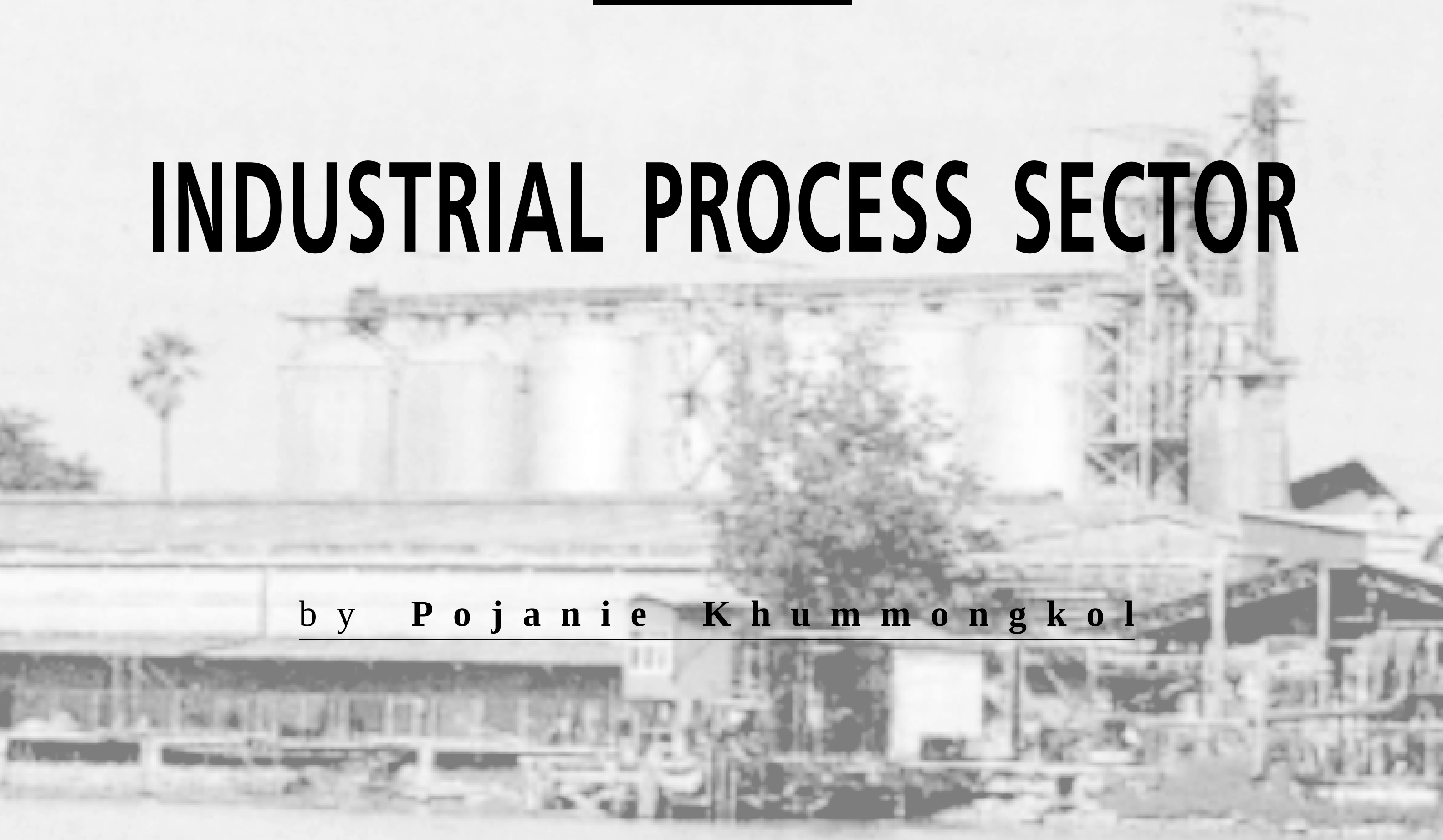
CHAPTER

2

INDUSTRIAL PROCESS SECTOR



by Pojanie Khummongkol

- Introduction
- Methodology
- Data
- Results

2.1 INTRODUCTION

GHGs are emitted as by-products of various production processes which involve the chemical or physical transformation of raw materials, and which are not related to energy combustion activities. By far the most significant GHG emission from industrial processes is CO_2.

The manufacturing sector takes the highest share of GDP of the country. In 1990, it accounted for 67.5 percent of total GDP, a share which had increased to 69.0 percent in 1994. This was accompanied by a growth in the number of manufacturers registered in the country, which was 103,574 in 1994.

This study estimates GHG emissions from production processes in eight industries, namely the cement, lime, glass, pulp and paper, iron and steel, petrochemical, and food and beverage industries, as they are being manufacturing in Thailand and the data are available. Due to limitation of the emission factors provided by the Revised 1996 IPCC Guidelines for National GHG Inventories, Volume 2, the types of GHG for the following industries shown in Table 2.1 are evaluated.

2.2 METHODOLOGY

GHG emissions from industrial processes occur not from energy-related activities but through production processes. Types of GHG emitted, therefore, depend on the nature of the manufacturing processes; i.e. quantities of raw materials consumed in the process, chemical reactions, and the conversion efficiency of the compound outputs. This section lists the type of industrial processes in Thailand and their GHG emission potentials.

Assumptions

GHG emissions from manufacturing processes are estimated using the following data:

(1) The production process for each specific industry

(2) Production output, which, if not available, will be based on the factory manufacturing capacity

(3) Emission factors for each specific production process, extracted from the Revised 1996 IPCC Guidelines for National GHG Inventories, Volume 2.

Table 2.1 A List of Industrial Processes evaluated for GHG emissions

Type of GHGs	Industrial Processes
CO_2	Cement production
	Lime production
CH_4	Chemical industry: Ethylene
NMVOC	Non-Metal production: Glass
	Chemical industries: Ethylene and Polypropylene
	Metal production: Steel
	Pulp and Paper industries
	Alcoholic beverage: Beer, Wine, Whiskey
	Food production: Bread
NO_x	Metal production: Steel
	Pulp and Paper industries
CO	Metal production: Steel
	Pulp and Paper industries

Calculations

$$TOTAL_{ij} = A_j \times EF_{ij}$$

Where:

$TOTAL_{ij}$ = the process emission (tonnes) of gas i from industrial sector j

A_j = the amount of activity or production of process Material in industrial sector j (tonnes/yr)

EF_{ij} = the emission factor associated with gas i per unit of activity in industrial sector j (tonne/tonne)

Cement Production

Raw materials used in the production of Portland cement include limestonne ($CaCO_3$), bauxite, aluminum dross, sand, and iron. These raw materials are finely ground, mixed, and heated in a rotary kiln to form cement clinker. The major concern in this GHG study is that during the calcination process which produces cement clinker, a large quantity of CO_2 is emitted. The reaction which takes place is

$$CaCO_3 + heat \longrightarrow CaO + CO_2$$

The mass balance for CO_2 emission is that for every 1 mole of $CaCO_3$ burned, 1 mole of CO_2 will be produced, or in terms of weight ratio: 0.4396 tonnes CO_2 per tonne $CaCO_3$ burned, or 0.7857 tonnes CO_2 per tonne CaO produced. Since clinker is mixed with gypsum, which contains less lime per unit, to make cement-clinker which has a higher lime content than finished cement, the emission factor in terms of per unit clinker is 0.5071 tonnes CO_2 per tonne clinker produced. The most convenient emission factor to use is expressed in tonnes CO_2 per tonnes cement, since data on cement production is reported annually. In this case, its value is 0.4985 tonnes CO_2 per tonne cement produced.

Lime Manufacturing

The production process of lime is similar to that of cement, in that CO_2 occurs via the calcination of limestone. The reaction equation is

$$CaCO_3 + heat \longrightarrow CaO + CO_2$$

The stoichiometric balance of the equation is 1 mole CO_2 per 1 mole $CaCO_3$. The emission factor for the process is 0.79 tonnes CO_2 per tonne quicklime produced.

Glass Production

95 percent of all glass manufactured in the world uses the soda-lime process. The raw materials used to make flat glass consist of: sand 47 percent, soda ash 16 percent, salt cake 6 percent, powdered coal 0.2 percent, lime 7 percent, cullet 23 percent, and other 0.8 percent by weight.

The general process reactions are:

$$Na_2CO_3 + aSiO_2 \rightarrow Na_2O \bullet aSiO_2 + CO_2 \quad (1)$$

$$aCO_3 + bSiO_2 \rightarrow CaO \bullet bSiO_2 + CO_2 \quad (2)$$

$$Na_2SO_4 + cSiO_2 + C \rightarrow Na_2O \bullet cSiO_2 + SO_2 + CO \quad (3)$$

To produce flat glass, the material mole ratio is 1.5 mole Na_2O: 1 mole CaO: 5 moles SiO_2.

The process mole balance equations for glass are:

$$1.5Na_2CO_3 + 5SiO_2 \rightarrow 1.5Na_2O \bullet 5SiO_2 + 1.5CO_2 \quad (1)$$

$$CaCO_3 + 5SiO_2 \rightarrow CaO \bullet 5SiO_2 + CO_2 \quad (2)$$

$$1.5Na_2SO_4 + 5SiO_2 + 1.5\ C \rightarrow 1.5Na_2O \bullet 5SiO_2 + 1.5SO_2 + 1.5CO \quad (3)$$

The mole balance is 2.5 moles CO_2 per 1.5 moles $Na_2O \bullet 5SiO_2$ produced. The emission factor for CO_2 in terms of unit weight is 0.1315 tonnes per tonne flat glass.

Emission Factors for CO_2 is not available by the IPCC. For other GHGs, only NMVOC is listed in the Revised 1996 IPCC Guideline with the value of 4.5 kg per tonne of product.

Pulping Process

The production of pulp and paper involves three major processing steps: pulping, bleaching and paper production. There are two main processes: Kraft pulping and the Sulphite pulping. In Thailand most of the pulping industries used the Kraft pulping process.

Primary raw materials required to produce 1 tonne of dry pulp in the Kraft or sulphite pulping processes are consisted of: Wood 1.5-2 tonnes, Lime 250 kg, and Soda ash 125 kg.

CO_2 evolves from the black liquor recovery process. The mole balance reactions are:

$$Na_2SO_4 + 2C \longrightarrow Na_2S + 2CO_2 \quad (1)$$

$$CaCO_3 + heat \longrightarrow CaO + CO_2 \quad (2)$$

The two equations above occur independently. The process mole ratios are 2 moles CO_2 per 1 mole Na_2SO_4 and 1 mole CO_2 per 1 mole $CaCO_3$. The emission factor of CO_2 per unit weight is 0.2072 tonnes per tonne of pulping product.

According to the Revised 1996 IPCC Guideline, the emission factor for NMVOC is 3.7 kg per tonne dried pulp.

Iron and Steel Production

Iron and Steel production in Thailand is a small-scale. The integrated facility (coke plus iron and/or steel production) was planned before the economic crisis but has been delayed since then. The process used in Thailand is through the pig iron purification process, in which the 3-4 percent carbon content in pig iron is reduced to less than 0.3 percent in order to increase iron quality. In the smelting process, approximately 10 percent of pig iron is mixed with scrap iron.

Since the domestic iron and steel productions are only a small-scale, prediction of CO_2 emission is difficult. In this category, only NMVOC is evaluated for the steel processing. The emission factor of this gas is 30 g per tonne steel produced.

Production of Other Chemicals

Emission factor data for petrochemical industrial processes are limited. The only values obtained are emissions of CH_4 for ethylene and NMVOC for polystyrene. They are

CH_4 for ethylene	1	kg/tonne ethylene
NMVOC for ethylene	1.4	kg/tonne ethylene
polystyrene	2.8	kg/tonne ethylene

Food and Drink

CO_2 from the use of biological carbon as feedstock and fermentation processes are not reported here because they are considered not to lead to net CO_2 emissions. The emissions of NMVOC are estimated for the bread processes. Emissions of NMVOC from alcoholic beverages include wine, beer, and grain whiskey.

Bread Production

The emission factor for NMVOC from bread is 8 kg per tonne of product.

Fermentation Processes

Grains and fruits containing carbohydrates are the basic raw materials in fermentation processes. The product of fermentation is alcohol which in beverage industries is divided into three groups: malt liquors, distilled liquors and fermented wines. Beer requires malted grain to make carbohydrates fermentable; wines are produced by the action of yeast on the sugar of fruits; and distilled liquors are fermented liquors which are then distilled to increase alcoholic content.

The emission factor for NMVOC from wine, beer and grain whiskey are 0.08, 0.035, and 1.5 kg per HL.

2.3 DATA

The data required for GHG emission estimations includes the number and types of existing industries in Thailand, the production capacities of the plants, the total raw materials used in the processes, and the emission factors. This section presents the data utilized in tables.

Cement Production

Cement is produced presently by nine manufacturers at a total output of 29.9 million tonnes in 1994.

Lime Manufacturing

Lime production capacities came from 20 provinces which conduct the calcination process of limestone. In 1994, there were 89 lime factories, with a total production capacity of 1.17 million tonnes.

Glass Production

Flat glass production in 1994, as reported by the Bank of Thailand (1995), was 483,743 tonnes.

Pulping Process

Presently, there are four kraft pulping factories with a total production capacity of 313,000 tonnes per year. Production of pulp in 1994 was 237,905 tonnes.

Iron and Steel Production

The production of iron and steel in 1994 was about 2.17 million tonnes. The production capacity has doubled within 5 years, despite an apparent shortage in the last few years.

Table 2.2 shows the production of cement, glass, lime, paper pulp, iron and steel in 1994.

Production of Other Chemicals

In 1994, there were 21 manufacturers in the petrochemical industry. Total production was 2.59 million tonnes, classified into up-stream, intermediate and down-stream production, up-stream production of ethylene, propylene and mixed C-4 has a total production capacity of 1,080,000 tonnes per year; intermediate production of vinyl chloride monomer has a total capacity of 280,000 tonnes per year; and down-stream production of polyethylene, polyvinyl chloride, polystyrene, polypropylene and acrylonitrile butadiend styrene, has a combined capacity of 1,225,000 tonnes per year.

Table 2.2 Cement, Glass, Lime, Paper Pulp, Iron and Steel Production, 1994 (tonnes)

Industry	Production
Cement	29,929,214
Glass	483,743
Lime	1,168,364
Paper Pulp	237,905
Iron and Steel	2,168,000

Source: Bank of Thailand (BOT), 1995.

Table 2.3 Production of Bread, Beer, Wine and Whisky in Thailand, 1994

Industry	Unit	Production
Bread[1/]	Tonnes	19,762
Beer[2/]	Thousand litres	521,649
Wine[1/]	Thousand litres	25,832
Whisky[2/]	Thousand litres	1,656,827

Source: [1/] Industrial Control Division, Department of Industrial Work, 1995.
[2/] Bank of Thailand (BOT), 1995

Since most of the emission factors for these processes are not available, only ethylene and polystyrene process emissions are evaluated here. The production capacity of ethylene was 315,000 tonnes per year and of polystyrene, 1,250,000 tonnes in 1994 (BOT, 1995).

Other Production

Four types of other industrial production were also included in the estimation of emissions from industrial processes. They were bread, beer, wine and whisky (Table 2.3)

In 1994, total bread production in Thailand was 19,762 tonnes while the total beer, wine and whisky production were 521.6, 25.8 and 1,656.8 million litres respectively.

2.4 RESULTS

Emissions of GHGs from industrial processes were estimated with the following results:

CO_2 Emission

The CO_2 emissions were from cement, lime, glass, pulping and iron and steel production processes. In 1994, cement production emitted about 14,920 Gg of CO_2 while the calcination process of limestone emitted about 918 Gg of CO_2 (Table 2.4). Glass production emitted about 64 Gg of CO_2. The CO_2 emissions from pulping and iron bar production processes were estimated as 49.3 Gg and 19.5 Gg respectively. The total CO_2 from these five industrial production processes was 15,970 Gg (Table 2.4).

CH_4, NO_x and NMVOC Emission

Glass production emitted a small amount of NO_x of 1.9 Gg in 1994, but did not emit CH_4. The sector emitted about 2,177 Mg of NMVOC while the iron and steel emitted 65 Mg. The production of ethylene emitted CH_4 and NMVOC at 315 and 441 Mg, respectively. Emission of NMVOC from polystyrene was estimated to be 4,175 Mg in 1994 (Table 2.5). In 1994, bread production process produced about 158 Mg of NMVOC while the beer, wine and whisky production emitted 18,258, 2,067 and 2,485,241 Mg of NMVOC respectively (Table 2.6).

Table 2.4 Emissions of CO_2 from Cement, Glass, Paper Pulp, Iron and Steel Manufacturing Processes, 1994 (Mg)

Industry	CO_2
Cement	14,920,001
Lime	917,984
Glass	63,612
Paper Pulp	49,294
Iron and Steel	19,512
Total	**15,970,403**

Table 2.5 Emissions of CH_4 and NMVOC from Glass and Petrochemical Industrial Processes, 1994 (Mg)

Product	CH_4 Emission	NMVOC
Glass	-	2,177
Iron and Steel	-	65
Ethylene	315	441
Polystyrene	-	4,175
Total	**315**	**6,858**

Table 2.6 Emissions of NMVOC from Fermentation Processes, 1994 (Mg)

Industry	NMVOC
Bread	158
Beer	18,258
Wine	2,067
Whisky	2,485,241
Total	**2,505,724**

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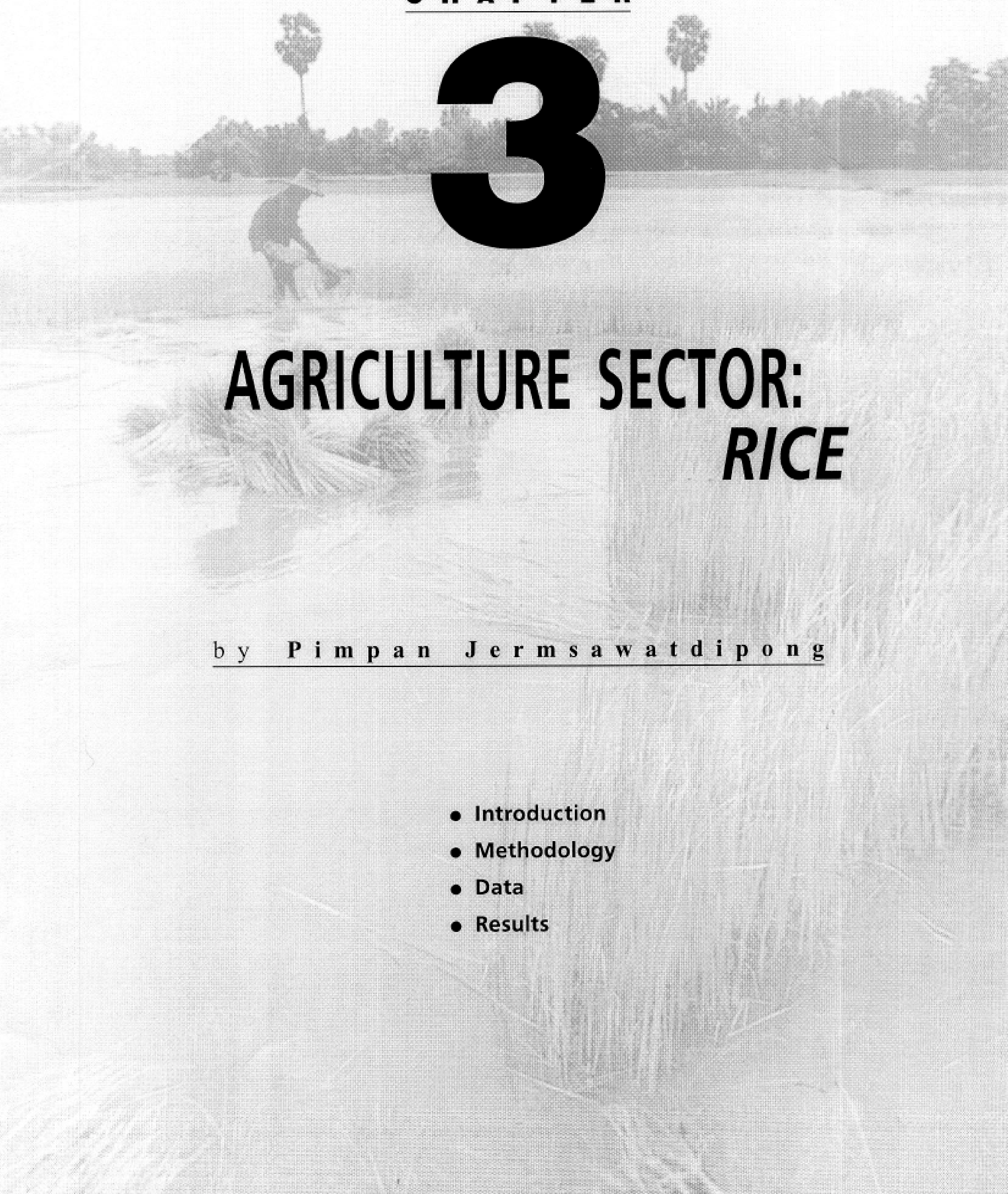

CHAPTER

3

AGRICULTURE SECTOR: *RICE*

by Pimpan Jermsawatdipong

- Introduction
- Methodology
- Data
- Results

3.1 INTRODUCTION

The global emissions of methane (CH_4) are estimated to be approximately 550 Teragrams (Tg) per year. Methane is recognized as one of the most important greenhouse gases and may account for 20 percent of anticipated global warming. Agriculture plays an important role in supplying CH_4 to atmosphere and is estimated to contribute more than 50 percent of anthropogenic emissions. Flooded rice fields, which occupy about 148 million hectares (Mha) of global area and produce about 475 Mt rice, emit about 11 percent of total global emissions of methane or 50-60 Tg CH_4 per yr. However, the uncertainty of these estimates is extremely high, ranging from 20-100 Tg CH_4 per yr. This is mainly due to the extreme spatial and temporal variability of fluxes and heterogeniety of soil, water and crop management practices, organic matter amendments and fertilization.

The emission of methane from paddy fields in Thailand for crop year 1990 were estimated by TEI (1997) at 1.786 Tg per year, which is equivalent to 65 percent of total country emission of methane or 15 percent of total country global warming potential (GWP). The GWP of CH_4 is about 21 times that of CO_2 in 100 years. This estimate was based on the Intergovernmental Panel on Climate Change (IPCC) methodology (IPCC, 1995) and local values for emission factors, cropping periods and harvesting area. When all the IPCC default values were used in the estimation, the country's total methane emission increased substantially to 4.4 Tg per year.

In this study, methane emission from paddy fields is estimated using the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). This version of the IPCC Guidelines recommends the inclusion of some of the factors that control methane emission from paddy fields. The factors clearly identified by field experiments as being most important are: (1) water regimes, (2) inorganic fertilizer application, (3) organic fertilizer application, (4) soil type and soil texture, (5) variety of rice cultivars, and (6) cultural practice such as transplanting or direct seeding.

Experimental data indicate that the continuous flooding of paddy fields, high carbon-nitrogen ratio (C/N) of organic fertilizer application, and use of traditional rice cultivars induce higher methane emission compared to intermittent flooding, and/or absence of organic fertilization. Paddy areas are thus subcategorized based on different biological, chemical and physical factors that control methane emission from paddy fields. In the latest IPCC guidelines, scaling factors that take into account the emissions from rice grown under different water regimes relative to continuous flooding are given. Many studies have also confirmed that the addition of organic matter to rice paddies strongly increases methane emission. Hence, a correction factor of 2-5 was recommended to convert the emission rate of methane from paddy soils without organic amendment to these with organic amendment.

At present, there is insufficient data on methane emission under such conditions in Thailand. The scaling factors for methane emission of rice cultivated under different water regimes and organic matter amendment proposed by the IPCC (IPCC, 1997) are therefore used in this estimation.

In the rice sector, emission projection and mitigation obtion analysis has also been discussed and the results are shown in the Appendix.

3.2 METHODOLOGY

This national inventory, which presents estimates of methane emission from rice cultivation for crop year 1994, is based on methodology provided in the latest IPCC Guidelines (IPCC, 1997). Emissions of methane from paddy fields under different water regimes and organic matter amendment were estimated independently and combined to represent the country's total emission.

The total area under rice cultivation, subcategorized into different water regimes, was obtained from the agricultural statistics of Ministry of Agriculture and Cooperatives (Agricultural Statistics,1994/95). Emission factors used were actual methane emission data as measured by Jermsawatdipong, *et al.* (1993).

Assumptions

The assumptions set out for this estimation of methane emission from paddy fields are as follows:

- **Base year.** The estimation of methane emission from paddy fields is based on the cultivation in the year 1994.
- **Paddy area.** Paddy areas include the harvesting areas for both major rice (wet season crop) and second rice (dry season crop).
- **Water regimes.** Major rice is planted in all 4 types of water regimes, namely, upland, irrigated (continuously flooded and intermittently flooded), rain-fed (flood prone and drought prone), and deepwater areas, while second rice is planted only under irrigated (continuously flooded) areas.

- **Irrigated area.** All harvesting areas under irrigated water regime are assumed to be continuously flooded. Fifty percents of irrigated paddy areas were incorporated with organic matter.
- **Fertilizer use.** Half of the irrigated paddy fields in the wet season and the entire area in the dry season are assumed to be amended with organic fertilizer.
- **Flood and drought prone areas.** Rice that is cultivated under rainfed water regime in the central and northern region of the country is prone to flooding, while rice cultivated in the northeastern region is subject to drought. Fifty percents of paddy areas were incorporated with organic matter.
- **Seasonal length.** Seasonal length is the period from transplanting to harvesting, which varies according to rice cultivars and cultural practices. It must be noted that seasonal length for photosensitive type of rice depends upon the planting date.

Calculation Method

The emission of methane from rice fields can be estimated using the following method, as recommended in the revised IPCC Guidelines (IPCC, 1997):

$$\mathbf{F_c = \Sigma_i\Sigma_j\Sigma_k\ EF_{ijk} \times A_{ijk} \times 10^{-12}}$$

where

F_c = estimated annual emission of methane from a particular rice ecosystem and for a given soil amendment in Tg per year;

EF = methane emission factors integrated over cropping season, in g per sq m (average emission rate in g per sq m per day x cropping period in days)

A = annual harvested area cultivated under conditions defined above in sq m per yr.

ijk = categories under which methane emissions from rice fields may vary.

The seasonally integrated emission factor is evaluated from direct field measurements of methane fluxes throughout the cropping season. The total annual emission from a country (F) is the sum of emissions calculated over a number of conditions that control methane emission from paddy fields (F_c). Category i may represent water regime such as continuously flooding, intermittent flooding and deep water, j and k may represent organic amendment, soil characteristics and fertilization regimes.

3.3 DATA

The revised IPCC methodology (IPCC, 1997) provided default scaling factors for water regimes and correction factors for organic amendments and local methane emission rate to estimate the annual emission of methane for crop year 1994. The emission factors used in the calculation were derived using the average of the measurements conducted in four typical rice growing areas in Thailand (0.2595 g-CH_4 per sq m per d) which were under continuous flooding in the wet season during 1992 to1994 (see Table 3.1). The average methane emission rate was converted according to different water regimes and organic matter amendment using IPCC correction factors given in Table 4-10 of the revised IPCC Guidelines. The emission factors for each subcategory are presented on Table 3.2.

Table 3.1 Measured Methane Emissions in kg CH_4/ha/day from Various Rice Cultivation Areas, with and without Soil Amendments

Province	Soil series	NF	CF	CF+OM	Average
Pathum Thani	Rangsit	0.45	0.73	1.11	0.763
Ratchaburi	Nakornpathom	1.13	2.32	5.93	3.127
Surin	Roi-et	3.77	5.41	6.33	5.170
Chiangmai	Hang Dong	0.89	1.76	1.31	1.320
Average		**1.56**	**2.56**	**3.67**	**2.595**

Notes: NF = no fertilizer application
CF = with chemical fertilizer amendment
CF + OM = with both chemical and organic fertilizer amendment

Source: Jermsawatdipong, *et al.* 1994.

Table 3.2 Methane Emission Factors for Different Water Ecosystem and Organic Amendment

Category	Sub-category		Scaling factors for rice ecosystem	Correction factors for organic amendment	Emission factors kg CH_4/ha/day
Major rice					
Upland	Rainfed	–	0	1	0
	Irrigated	Continuously flooded + OM	1	2	3.120
		Continuously flooded	1	1	1.560
Low land	Rainfed	Flood prone	0.8	2	1.248
		Flood prone + OM	0.8	1	2.496
		Drought prone	0.4	1	0.624
		Drought prone + OM	0.4	2	1.248
	Deep water	Water depth > 100 cm	0.6	1	0.936
Second rice	Irrigated	Continuously flooded + OM	1	2	3.120

The estimate of methane emission was also made using local emission factors measured specifically from the plots with organic amendment. The average emission rate measured from the plot amended with both chemical fertilizer and organic fertilizer (3.67 g-CH_4 per sq m per day) was used in area where rice was applied with organic matter (both planted under irrigated and rain-fed conditions). For areas where no organic matter was applied, the emission factor of the plot with no fertilizer application (1.56 g-CH_4 per sq m per day) was used. The emission factor used for deep water rice was the average of emission factors measured over 4 years period from deepwater rice planted in acid sulfate soil in Prachinburi province (0.046 g-CH_4 per sq m per day, Charoensilp, *et al*. 1998).

3.4 RESULTS

Using the average value of local emission factors for non-fertilized paddy fields (1.56 kg-CH_4 per ha per day) and IPCC's default scaling factors for different water regimes and organic amendment, the total emission of CH_4 from paddy fields in Thailand in year 1994 was estimated at 1.878 Tg-CH_4 (see Table 3.3). It is evident that major rice cultivation, which occupies about 93 percent of total harvesting area, contributed the largest amount (83 percent) of the country's total methane emissions, while second rice production contributed only 7 percent. Rice planted under rainfed ecosystem in the wet season, when cultivation area extends to 69 percent of the total, contributed 52 percent of methane emissions, while the smaller area under irrigated conditions emitted about 34 percent.

This revised IPCC estimation method results in slightly lower country emissions of methane, compared to the estimation method that uses local emission factors and scaling factor for water regimes. Under the latter method, which assigns local emission factors specifically for each cropping condition, the estimated total methane emission is 2.11 Tg-CH_4 (see Table 3.4). The emission rate used for deepwater ecosystem is the measured value locally obtained from deepwater rice cultivated in Prachinburi province (Charoensilp, *et al*. 1998).

Table 3.3 Methane Emission from Paddy Fields in Thailand (Estimates Based on 1996 IPCC Scaling Factors for Rice Ecosystem and Correction Factors for Organic Amendment and Country Emission Data)

Category	Sub-category		Emission factors (kg CH_4/ha/day)	Cultivation area (ha)	Cropping period (day)	CH_4 emission (Gg)
Major rice						
Upland	Rainfed	–	0	34,048	136	0
Low land	Irrigated	Continuously flooded + OM	3.120	1,121,492	120	420
		Continuously flooded	1.560	1,121,492	120	210
	Rainfed	Flood prone	1.248	1,100,926	120	165
		Flood prone + OM	2.496	1,100,926	120	330
		Drought prone	0.624	2,184,333	120	164
		Drought prone + OM	1.248	2,184,333	120	327
	Deep water	Water depth > 100 cm	0.936	39,478	210	8
		Total		**8,887,026**		**1,623**
Second rice	Irrigated	Continuously flooded	3.120	680,123	120	255
		Total Emissions		**9,567,149**		**1,878**

Table 3.4 Methane Emission from Paddy Fields in Thailand (Estimates Based on Locally Measured Methane Emission Factors)

Category	Sub-category		Seasonal flux (g CH_4/sq m)	Cultivation area (ha)	CH_4 emission (Gg)
Major rice					
Upland	Rainfed	–	0.00	34,048	0.00
Low land	Irrigated	Continuously flooded + OM	44.04	1,121,492	493.90
		Continuously flooded	18.72	1,121,492	209.94
	Rainfed	Flood prone + OM	14.98	1,100,926	164.87
		Flood prone	35.23	1,100,926	387.88
		Drought prone + OM	17.62	2,184,333	384.79
		Drought prone	7.49	2,184,333	163.56
	Deep water	Water depth > 100 cm	15.31	39,478	6.04
		Total		**8,887,026**	**1,811.00**
Second rice	Irrigated	Continuously flooded	44.04	680,123	299.53
		Total Emissions		**9,567,149**	**2,110.53**

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APPENDIX

Projection and Mitigation

Introduction

The results show that a large proportion of methane emissions during the wet season was released from irrigated areas (43 percent). The large cultivation area under rain-fed ecosystem also emitted about 39 percent. Moreover, when the cultivation of rice in both cropping seasons was considered, the areas under irrigation emitted about 61 percent of total methane emissions.

Methane emissions can be reduced effectively from irrigated areas through various measures experimentally conducted in other countries. However, these methane emission mitigation strategies should neither cause a significant reduction in yield nor increase production cost.

Anticipated Trends in Methane Emission

According to the policy prepared by the Office of Agricultural Economics in 1993, the major rice cultivation area will stabilize at around 8.8 million hectares, while the second rice crop grown in upland paddies will be reduced from 0.608 to 0.462 million hectares during the period from 1994 to 2001. To achieve this goal, rice productivity (grain yield per area) must increase to meet the demand for local consumption and export. Projections of rice productivity and cultivated area, as prepared by the Office of Agricultural Economics, are shown on Table A3.1.

Assuming that rice cultivation areas from 1994 to 2020 are as outlined by the government, the increase in rice production could be achieved by various soil and fertilizer management technologies. Further assuming that irrigation area for rice cultivation increases steadily at the rate of 1 percent per year, and that the usage of both chemical and organic fertilizer increases to maximize the grain yield of rice, the cultivation area with fertilizer application would expand at the rate of 20 percent per year.

Possible Mitigation Options for CH_4 Emission from Paddy Fields

Based on extensive studies conducted by several investigators from the United States, Japan, China, Korea, the Philippines, Germany and the International Rice Research Institute, a number of feasible options to mitigate methane emission have been proposed. Following are the possible options:

Water Management. Reduction of CH_4 emission from paddy fields can be achieved by aeration of paddy fields. This can be achieved either by draining flooded water from irrigated paddy fields or by stop applying irrigation water periodically. However, one must be aware that, at the same time, such aerated soil condition is favorable to nitrous oxide emission. Multiple soil aeration for a few days at 3, 4 and 6 weeks after initial flooding has been found to reduce methane emissions by 88 percent and did not effect crop yield, though it required 2.7 times more water than normal irrigation (Sass, *et al*.

Table A3.1 Projections of Rice Production and Cultivation Area Based on Local Demand and Exports, 1994-2020

Year	Production (million tonnes)			Planting Area (million ha)		Average
	Consumption	Export	Total	Major Rice	Second Rice	Yield, kg/ha
1994	13.579	6.060	19.639	8.800	0.608	2,087
1995	13.747	6.060	19.807	8.800	0.590	2,109
1996	13.913	6.060	19.973	8.800	0.556	2,135
1997	14.368	6.060	20.428	8.800	0.528	2,190
1998	14.485	6.060	20.545	8.800	0.496	2,210
1999	14.659	6.060	20.719	8.800	0.493	2,230
2000	14.776	6.060	20.836	8.800	0.470	2,248
2001	14.950	6.060	21.010	8.800	0.462	2,269
2005	15.425	6.060	21.485	8.800	0.462	2,320
2010	16.018	6.060	22.078	8.800	0.462	2,384
2015	16.612	6.060	22.672	8.800	0.462	2,448
2020	17.205	6.060	23.265	8.800	0.462	2,512

Source: Office of Agricultural Economics, 1993

1992). A single aeration during mid-tillering or late tillering stage has also been found to decrease methane emissions by more than 50 percent compared with continuous flooding (Kimura, 1992, Javellana, *et al.* 1995, Wang, *et al.* 1996, Wangfang, *et al.* 1996).

Organic Matter Amendment. As demand for rice consumption increased, organic matter amendment has been recognized as beneficial to crop production (both in quantity and quality) for thousand of years. In Thailand, the Rice Soil and Fertilizer Research Group, Soil Science Division, Ministry of Agriculture and Cooperatives has conducted a number of long-term experiments to improve crop productivity by incorporating various types of organic matter into paddy soil, including farm residues, farm residue compost, green manure and animal manure. The incorporation of green manure from plants such as mungbean, soybean, Sesbania and Azolla has been found to significantly increase rice production and improved soil properties, particularly in sandy textured soil and saline soil in the northeast of the country.

The incorporation of organic matter into flooded paddy soils increases methane emission from all soil types by providing a carbon source for methanogens. Experiments conducted in Thailand have indicated that the incorporation of only 2 percent of dry rice straw in acid sulfate soil increased methane emissions markedly from 0.45 to 1.11 g-CH_4 per sq m per day, while the incorporation of green manure plant, Sesbania rostrata, into clayey soil increased emissions from 1.13 to 5.93 g-CH_4 per sq m per day (see Table 3.1). Similar effects of organic matter incorporation into soils were observed by Lauren and Duxbury (1993) and Sass, *et al.* (1991b). The effect of organic matter incorporation on methane emission is acknowledged by IPCC (1997). The panel therefore recommends a default correction factor of 2 for methane emission conversion in paddy soils with organic amendment, which is used in the estimation of methane emission from rice cultivation in this report.

The addition of organic matter rich in easily decomposable carbon such as green manure, rice straw, and farmyard manure into flooded soil causes an increase in methane emissions and should be minimized. Incorporation with pre-fermented farm residues, animal waste or compost has been found to cause less methane emissions (Yagi and Minami, 1990, Teodula and Bajita, 1998, Wangfang and Wei, 1998, Goutam, *et al.* 1996), but required more labor in the production process and delivery to farms.

Mineral Fertilization. Nitrogen is an essential plant nutrient and one of the significant constituents of all proteins, chlorophyll and coenzymes and nucleic acids. Nitrogen promotes rapid growth, especially the development of leaves and stems. It is normally lacking in rice fields, hence the application of different types of nitrogenous fertilizer into paddy fields. However, such application affects the emission of nitrous oxide and methane gas.

Urea is the most common nitrogen fertilizer used for top dressing at panicle initiation stage of plant growth in Thailand, comprising of 75-80 percent of the total. Instead of urea, though, ammonium sulfate or ammonium nitrate applied to flooded paddy soils has been found effective in suppressing methane production. The efficiency increases if applied also as basal fertilizer at the early tillering stage. The oxidized components such as sulfate and nitrate tend to buffer soil redox potential (Eh), slowing down methane formation.

The efficiency of sulfate-containing nitrogen fertilizer in reducing methane emission is highly dependent on soil properties, particularly soil pH and mode of application. Surface application of ammonium sulfate was observed to reduce methane emission more efficiently than incorporation into soil (Patrick and Delaune, 1997). But deep application of urea was found to decrease methane emission by as high as 23 percent compared to that of broadcasting on soil surface (Makarim and Setyanto, 1998) since it increases the efficiency of nitrogen fertilizer by reducing the evaporation loss of nitrogen as ammonia. In the Philippines, results from a series of field experiments indicated that paddy fields with ammonium sulfate application reduced methane emission by as high as 60 percent (Buendia *et al.*, 1998). The addition of urea with phosphogypsum can also decrease emission by 74 percent (Teodula and Bajita, 1998).

The widespread use of ammonium sulfate is inhibited not only by its availability and price but also by its impact on soil acidity. Farmers prefer urea to ammonium sulfate for its easy handling and broadcasting to the paddy. The quantity of ammonium sulfate used for rice cultivation varies from year to year depending on the market price. The average amount used during 1989 to 1994 was only about 28 percent that of total nitrogen fertilizer used.

Rice Cultivars. The production and emission of methane into the atmosphere appear to depend on rice plant characteristics, not only in terms of their capacity for transporting methane from roots into the atmosphere but also in the ability of the root themselves to exude carbon compounds. Degrading leaves and roots are important sources of organic carbon, especially at later stage of plant growth.

In general, traditional rice varieties emit less amount of methane than modern varieties. Field experiments conducted in Thailand found that traditional deep water rice emitted 50.4 mg-CH_4 per sq m per day while the modern rice variety (IR72) planted in the same soil under continuously flooded conditions emitted a higher amount of methane of 93.2 mg-CH_4 per sq m per day (Charoensilp, *et al.* 1998). A study in Beijing also found that short grain Japonica rice emitted higher amounts of methane than Indica rice. The emission of methane also varies with water regimes (Jain and Kumar, 1998). For example, when planted under continuously flooded conditions, the modern rice variety (IR72) emitted 19.7 mg-CH_4 per sq m per day, while traditional varieties Pusa and Pusa Basmati emitted 10.85 mg-CH_4 per sq m per day. But under intermittently flooded conditions, methane emission from the traditional rice varieties increased to 11.69 mg-CH_4 per sq m per day while that for the modern rice variety decreased to 8.45 mg-CH_4 per sq m per day.

These findings suggest that an intensive study must be conducted to select the low methane emission varieties and to identify the factors that may potentially reduce methane emission.

Cultural Practices. Land preparation, especially puddling, transplanting of rice seedlings, weeding, and fertilizer application in the flooded paddy fields cause soil disturbance which releases trapped CH_4 into atmosphere. Transplanting rice seedlings is a common practice employed in Thailand, though recently the government has encouraged the planting of seeds directly onto the soils for irrigated rice. Less soil disturbance is made by the direct seeding method compared to the transplanting method, thereby reducing the amount of methane emission to some degree.

Dry direct seeding method is presently increasing in popularity. The harvesting area for dry direct seeding had increased remarkably from about 14 percent to 24 percent of the total area for major rice production between 1989 and 1991, while the area for transplanting decreased from 74 percent to 65 percent during the same period. This planting method not only reduces the release of entrapped methane and period of methane formation but also increases the efficiency of water use. Thus the target areas are those under irrigation.

Methane Production Inhibitors. Chemical compounds inhibiting CH_4 production are being investigated. Some of the effective chemicals are sulfate compounds such as calcium sulfate or gypsum, sodium sulfate, and sulfate containing fertilizers as phosphogypsum and ammonium sulfate (Lindau, *et al*. 1993). Neue (1994) observed that between 55-70 percent of CH_4 emission is reduced from soil amended with 6.66 tons per hectare of gypsum. In other studies, the slow release of acetylene from calcium carbide, encapsulated in fertilizer granules, greatly reduced CH_4 emission (Bronson and Mosier, 1991). The main limitations for the use of these inhibitors are cost and availability. At present, the cost of gypsum in Thailand is almost the same as ammonium sulfate.

Using methylfluoride as methane inhibitor in field investigations showed that methanotrophic bacteria can consume more than 90 percent of the methane potentially available (Oremland and Culbertson, 1992). In another experiment, the addition of a nitrification inhibitor, dicyandiamide, at the rate of 3 kg per ha was found to reduce methane production (Adhya, *et al*. 1998). Experiments conducted in India by Sethunathan, *et al*. (1998) showed that carbamate insecticide, carbofuran, and organochlorine insecticide, hexachlorocyclohexane, when applied to paddy fields appeared to inhibit CH_4 emission.

Crop Rotation Systems. Neue, *et al*. (1995) suggest that the rotation of rice crop with other upland crops is a feasible option to reduce total annual CH_4 emission. It also helps to increase crop production and income particularly in the intensive rice production areas. The production of rice in areas where irrigation is available all year round is generally increased by growing rice 2 times per year or 5 times per 2 years in the central region of Thailand. Neue, *et al*. (1995) recommended to reduce CH_4 emission by growing other upland crops as rotation crops before or after one or two crops of rice. Various upland crops which can be grown in the paddy field before rice cultivation are baby corn, mungbean, cowpeas. After rice cultivation, soybean, corn, cowpeas, chicken bean and mungbean can also be grown. The sequences of cropping rotation applicable to any region should be investigated. For example, an experiment conducted in Korea shows that planting alfalfa in winter before rice significantly increases CH_4 emission than wheat or fallow (Xu and Cai,1998).

Proposed Mitigation Strategies

Methane emissions are expected to increase as rice production expands to meet the growing demand for consumption. This would mean increasing rice yields through soil and fertilizer management and by breeding high yield rice varieties. In Thailand, the major source of methane emission is from rice cultivation during the wet season. Moreover, emission per cultivation area is evidently greater in irrigated areas than in rain-fed areas. With several mitigation technologies already identified, two possible strategies are being proposed for implementation in Thailand:

Methane emission can be prevented or reduced in areas where mitigation technologies can be applied. This approach can be employed in the cultivation of irrigated rice using a single technology or a combination of technologies.

The reduction of methane emission in areas where rice cultivation is a necessity and therefore methane emission can not be avoided. This approach can be applied to rain-fed rice cultivation areas, particularly in the unfertile paddies. The incorporation of organic matter has been proven essential for yield improvement, crop nutrition nourishment and, more importantly, for increasing soil buffering capacity and for improving the physical properties of poor soil. The type, amount and application mode of organic matter must be further investigated locally in relation to methane production and emission.

To reduce methane emission from paddy fields in Thailand, the possible technical options are:

Option 1: **Water management in irrigated areas**. This approach to mitigate methane emission can be applied effectively to irrigated rice, where the water resource is reliable throughout the cropping season. The possible target areas are those classified in group 1 to 3 of the Royal Irrigation Department project (see Table A3.2), which occupy about 87 percent of the total irrigated area. If the water management technique is adopted and implemented in the target area and is assumed to result in a 50 percent reduction in methane emission, total country emission of methane could be brought down to 1.57 Tg-CH_4, equivalent to about 26 percent reduction (Table A3.2).

Option 2: **Improvement of fertilizer amendment**. This mitigation option involves the use of pre-fermented organic matter instead of green manure or readily decomposable organic matter as well as the use of ammonium sulfate as nitrogenous fertilizer instead of urea. Assuming that the application of these soil amendments reduces methane emission by 19 percent, the country's total emission of methane would decline to 1.702 Tg-CH_4 or a 12 percent reduction from the base year (Table A3.3).

Option 3: **Water management and improvement of fertilizer amendment**. This methane mitigation technology includes options 1 and 2. When these two technologies are implemented for rice cultivated in both irrigated and rainfed areas, total country methane emission decreases to 1.345 Tg-CH_4, equivalent to a 36 percent reduction (Table A3.3).

Table A3.3 shows some estimates of methane emission from paddy fields from 1994 to 2020. Although the rice cultivation area remains constant, methane emission is predicted to increase from 1994 to 2020 due to the increase in irrigated area (assuming increasing at 1 percent per year) and fertilizer application. The increase in total emissions from 1994 to 2020 ranges from 5 percent in the base case to the lowest of 1.14 percent in option 3. With the application of methane mitigation technologies to rice fields, option 1 appears to be more effective than option 2. The combination of options 1 and 2 results in lowest methane emissions, equivalent to a decrease of more than 50 percent compared to the base case.

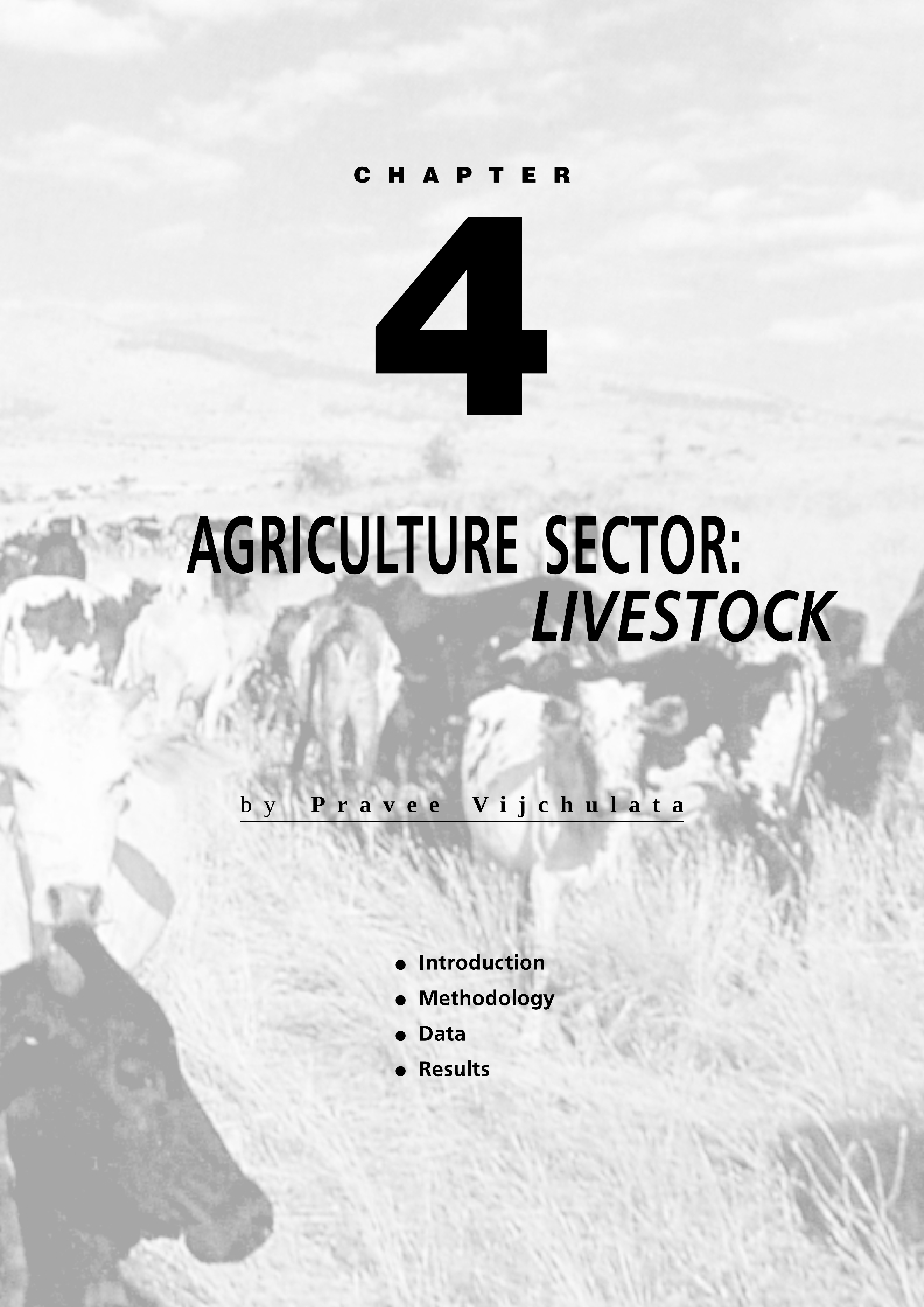
Table A3.2 Irrigated Rice Cultivation Area for Major Rice Classified by the Royal Irrigation Department

Class	Description	Area (ha)	Percent
1	Irrigated paddy land with abundant irrigation water, complete installation of contour structure.	251,955	10.19
2	Irrigated paddy land with abundant irrigation water, installation of irrigation wall and feeder canals.	1,088,735	44.05
3	Irrigated paddy land with abundant irrigation water, without installation of contour structure, nor irrigation wall and feeder canals.	820,857	33.21
4	Irrigated paddy land with protection against disaster of flood, seepage of brackish water, or other irrigated paddy land with insufficient irrigation water.	310,016	12.55
Total Area		**2,471,563**	**100.00**

Source: Royal Irrigation Department, 1994

Table A3.3 Projections of Methane Emission from Paddy Fields with Mitigation Options (Tg)

Year	Base case	Option 1	Option 2	Option 3
1994	2,111	1,570	1,702	1,346
2000	2,040	1,575	1,722	1,348
2005	2,063	1,579	1,739	1,350
2010	2,087	1,583	1,757	1,353
2015	2,113	1,588	1,777	1,355
2020	2,139	1,593	1,797	1,358



CHAPTER

4

AGRICULTURE SECTOR: *LIVESTOCK*

by **Pravee Vijchulata**

- **Introduction**
- **Methodology**
- **Data**
- **Results**

4.1 INTRODUCTION

Animal production is essential to the diet as well as the economy of the Thai population. In 1990, total production from livestock and poultry alone in the country was estimated at 64,450 million baht, representing about 22 percent of total agricultural farm-gate value (Office of Agricultural Economics, 1993). From the 5^{th} to 7^{th} National Economic and Social Development Plans, the animal production sector grew progressively at the rate of about 9 percent per annum (Division of Agricultural Research, 1995). Owing to the increased production of feed grains, the availability of crop residues and feed related industrial wastes, it is believed that the animal industry will continue to grow at an accelerating pace. Increasing world market demand for agricultural products will further stimulate the growth of the animal industry in Thailand.

Adverse environmental effects from animal production activities are well recognized. Of recent concern are greenhouse gas emissions, particularly methane and nitrous oxide, from livestock farming enterprises. Methane gas is produced from enteric fermentation of feed and from animal feces while nitrous oxide is produced from manure management. Since the contribution of livestock production towards GHG emissions in Thailand is still largely unknown, the objective of this study is to evaluate the situation.

Emissions of methane from enteric fermentation is estimated from dairy cattle, non-dairy cattle and buffalo and from the manure of ruminants as well as swine and poultry. In addition, nitrous oxide emissions are estimated from various manure management systems. The base year estimate for GHG emissions from animal production activities in this study is 1994 and follows the estimation techniques described by IPCC (1996).

The inventory of the animal population comes from the annual statistical reports of the Department of Livestock Development (1997). The estimation of methane gas production follows the procedures outlined by IPCC (1996). Two approaches are used: Tier 1 is recommended for GHG production estimation from animals which exist in small numbers, while Tier 2 is recommended for animals existing in large numbers.

Mitigation strategies of the livestock sector are discussed in the Appendix.

4.2 METHODOLOGY

Rationale

The primary GHG emissions from livestock are methane and nitrous oxide. Methane derives from feed digestive processes, mainly in ruminants, and from animal manure, while nitrous oxide derives from animal waste management. Enteric fermentation in herbivores produces methane as a by-product of the digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the blood stream. Both ruminant animals (e.g. cattle, buffalo) and some non-ruminant animals (e.g. pigs) produce methane, but ruminants are the largest source.

Methane and nitrous oxide emissions from the management of livestock manure occur as a result of its decomposition under anaerobic conditions. These conditions often occur when a large number of animals are managed in a confined area, e.g., dairy farms, beef feedlots, swine and poultry farms.

The amount of GHG produced from both sources depends upon various factors including animal species and body size, quantity and quality of feed digested, level and type of animal produces and environmental conditions. The estimation of methane gas emissions, therefore, has to take all these influencing factors into consideration.

Measurement of the enteric methane emitted can be conducted directly through the use of a face mask or respiratory chamber. However, both require animal involvement as well as special facilities and instrumentation. The alternative method is to indirectly calculate the amount of gas produced through the use of emission factors, which estimate the amount of energy intake that is converted into methane. Conversion factors can be used to estimate the amount of methane produced from animal manures. Similarly, emission factors are used to estimate the amount of nitrous oxide released from various manure management systems.

Assumptions

1. All dairy cattle are stall-fed, while non-dairy cattle and buffalo are allowed to graze in the open field. The feeds for all ruminants are assumed to attain 60 percent digestibility with 8 percent manure ash content.
2. All cattle are not used as draft animal, while mature female and male buffalo are assumed to work for 0.55 and 1.37 hours per day, respectively (IPCC, 1996).

3. Body weight and daily weight gain for different age groups of ruminants were derived or estimated from the reports of Chatalakhana (1984), Rattanaronchart (1972) and Songprasert (1974).
4. An average milk yield of 9.52 kg per head per day with 3.8 percent milk fat is estimated for dairy cows (Department of Livestock Development, 1997), 1.1 kg per head per day with 4.2 percent milk fat for non-dairy cows, and 0.15 kg per head per day with 7.0 percent milk fat for buffalo cows (IPCC, 1996).

4.3 DATA

Animal populations in 1994, shown on Table 4.1, are derived from the report of the Department of Livestock Development (1997). The number of female dairy cattle, by age group, represents the actual survey figures from these reports, while male dairy cattle, which exist in insignificant numbers, are included in non-dairy cattle. Among the remaining large ruminants, the ratios of female to male animals are 68:32 for non-dairy cattle, and 63:37 for buffalo (derived from the Department of Livestock Development, 1994). Additionally, a female to male ratio of 50, 17, 17 and 16 is used to estimate the number of animals in the four respective age groups for both animal types (Tumwasorn, 1993). Owing to the small population number, GHG emissions from goat and sheep are omitted.

Calculation

Methane emissions from enteric fermentation and from animal manure are estimated according to IPCC (1996). The estimation approaches for different animal types in this study are shown on Table 4.2. As recommended by IPCC, Tier 1 is used to estimate methane emissions from feed fermentation in animals with a small population. For animals with large numbers, Tier 2 is applied.

For Tier 1, methane production from the enteric fermentation process is calculated with the following formula:

$$\mathbf{E_{1f} = \Sigma\ (animal\ population_t \times EF_{ft})}$$

where:

E_{1f}	=	methane emission volume (kg/yr)
Animal $population_t$	=	average population of animal type t (head/yr)
EF_{ft}	=	enteric fermentation emission factor for animal t

In this study, the enteric fermentation emission factor (EFf) for Tier 1 follows the recommendations of IPCC (1996) for developing countries. However, the factors for developed countries are used for swine. The emission factors for swine under Tier 1 as recommended by IPCC (1996) is 1.5 kg per head per year.

Table 4.1 Number of Livestock in Thailand, 1994

Ruminants			Non-ruminants	
Dairy	Non-dairy	Buffalo	Swine	Poultry
265,873	7,371,477	4,224,791	8,479,400	151,808,913

Source: Department of Livestock Development (1997)

Table 4.2 Methods Used to Estimate Methane Emissions from Various Animal Types

Animal Types	Enteric Fermentation	Manure
Dairy Cattle, Non-dairy Cattle, Buffalo	Tier 2	Tier 2
Swine	Tier 1	Tier 2
Poultry	-	Tier 1

For Tier 2, emission factors for each type of animal are calculated from the energy intake and methane conversion rate, which is recommended at 6 percent by IPCC (1996), as follows:

$$\mathbf{EF_{2ft}\ (kg/yr) = [GE\ (MJ/day) \times Ym \times (365\ days/yr)] \,/\, (55.65\ MJ/kg\ CH_4)}$$

where:

EF_{2ft} = emission factor for animal type t
Ym = methane conversion rate (= 0.06)
GE = gross energy intake, which is estimated using the following equation:

$$\mathbf{GE\ (Mj/day) = \frac{\dfrac{(NE_m + NE_{feed} + NE_l + NE_{draft} + NE_{preg})}{NE / DE} + \dfrac{NEg}{NEg / DE}}{(DE\% / 100)}}$$

where:

NE = net energy
NE_m = net energy for maintenance
NE_{feed} = net energy for feeding
NE_l = net energy for lactation
NE_{draft} = net energy for draft
NE_{preg} = net energy for pregnancy
NE_g = net energy for gain
DE = digestible energy

NE_m is estimated from the equations:

lactating dairy cows

$$\mathbf{NE_m\ (MJ/day) = 0.335 \times (Body\ weight)^{0.75}}$$

remaining cattle and buffalo

$$\mathbf{NE_m\ (MJ/day) = 0.322 \times (Body\ weight)^{0.75}}$$

NEfeed is estimated from the equations:

lactating dairy cows

$$\mathbf{NE_{feed}\ (MJ/day) = 0}$$

remaining cattle and buffalo

$$\mathbf{NE_{feed}\ (MJ/day) = 0.37 \times NE_m}$$

NE_l is estimated from the equation:

all types of lactating animal

$$\mathbf{NE_l\ (MJ/day) = Milk\ yield\ (kg/day) \times (1.47 + 4.0\ (Fat\%)}$$

NE_{draft} is estimated from the equations:

all cattle

$$\mathbf{NE_{draft}\ (MJ/day) = 0}$$

mature buffalo

$$\mathbf{NE_{draft}\ (MJ/day) = 0.10 \times NEm \times Work\ (hrs/day)}$$

NEpreg is estimated from the equation:

$$\mathbf{NE_{preg}\ (MJ/281\ days\ period) = 28 \times Calf\ birth\ weight\ (kg)}$$

where:

$$\mathbf{calf\ birth\ weight\ (kg) = 0.266 \times (animal\ weight,\ in\ kg)^{0.79}}$$

NE_g is estimated from the equation:

$$\mathbf{NE_g\ (MJ/day) = 4.18 \times \{0.035 \times (body\ weight)^{0.75} \times (weight\ gain)^{1.119} + (weight\ gain)\}}$$

NE/DE is estimated from the equation:

$$\mathbf{NE/DE = 0.298 + (0.00335 \times DE\%)}$$

NE_g/DE is estimated from the equation:

$$\mathbf{NE_g/DE = -0.036 + (0.00535 \times DE\%)}$$

Finally, the total methane emission from enteric fermentation of feed in Tier 2 is calculated as follows:

$$\mathbf{E_{2f} = \Sigma\ (Animal\ population_t \times EF_{2ft})}$$

where:

E_{2f} = methane emission volume (kg/yr)
Animal $population_t$ = average population of animal type t (head/yr)
EF_{2ft} = emission factor for animal t

Methane emissions from livestock manure are also estimated according to the recommendations of IPCC (1996). As indicated on Table 4.2, Tier 1 is used to estimate fecal methane production from goats, sheep, horses and poultry, while Tier 2 is applied to those from dairy cattle, non-dairy cattle, buffalo and swine.

For Tier 1, fecal methane emission is estimated as follows:

$$\mathbf{E_{tw} = \Sigma\ (animal\ population_t \times EF_{tw})}$$

where:

E_{tw} = total fecal methane emission from manure (kg/yr)
Animal $population_t$ = average population of animal t (head/yr)
EF_{tw} = emission factor of animal manure t

According to IPCC (1996), the emission factor of poultry manure for developing countries with warm climates is 0.023 kg per head per year.

For Tier 2, fecal emission of methane gas is estimated as follows:

$$\mathbf{EF_{2t} = VS_t \times 365\ days/yr \times B_{ot} \times 0.67\ kg/m^3 \times \Sigma(MCF_{jk} \times MS\%_{ijk})}$$

where:

- EF_{2t} = emission factor (kg/yr) for animal type t
- VS_t = volatile solid produced (kg/day) for animal t
- B_{ot} = methane producing capacity (m^3/kg of VS) for manure produced by animal t
- MCF_{jk} = methane conversion factor for manure management system j by climate region k
- $MS\%_{jkt}$ = fraction of animal type t under manure system j by climate region k

Volatile Solid (VS) is estimated from the equation:

$$\mathbf{VS\ (kg\ DM/day) = GE\ (MJ/day) \times (1\ kg/18.45\ MJ) \times (1\text{-}DE\%/100) \times (1\text{-}Ash\%/100)}$$

The methane producing capacities (B) of the manure of cattle, buffalo and swine applied in this study are presented on Table 4.3. Additionally, methane conversion factors (MCF) for different manure management systems and the proportion of manure handling systems (MS) used for each type of animal are shown on Table 4.4. Meanwhile, Table 4.5 and Table 4.6 illustrates the methane and nitrous oxide emission conversion factors for manure from various animals.

Following the IPCC recommendation for Tier 1, the gross energy intake (GE) of swine for developed countries at 38 MJ per day is used in the calculation. Similarly, the digestible energy (DE) of feed and ash content of manure from swine is 72 MJ per day and 2 percent, respectively.

Nitrogen oxide emissions from animal waste management systems (AWMS) are estimated (Table 4.7) according to IPCC (1996) as follows:

$$\mathbf{N_2O_{awms} = \Sigma\ [\ Nex_{awms} \times EF_{awms}\ ]}$$

where:

- N_2O_{awms} = N_2O emissions from animal waste management systems (kg N/yr)
- EF_{awms} = N_2O emission factor for an AWMS (kg N_2O-N/kg Nex in AWMS)

Nex_{awms} is estimated from:

$$\mathbf{Nex_{awms} = \Sigma\ [\ N_t \times Nex_t \times AWMS_t\ ]}$$

where:

- Nex_{awms} = N excretion per Animal Waste Management System (kg/yr)
- N_t = number of animal of type t in the country
- Nex_t = N excretion of animals of type t in the country (kg N/Animal/yr)
- $AWMS_t$ = fraction of Nex t that is managed in one of the different animal waste management systems for animal of type t in the country
- t = type of animal

Table 4.3 Methane Producing Capacities (B_o) of Manure from Livestock

Animal Types	B_o (m^3/kg VS)
Dairy cattle	0.13
Non-dairy cattle	0.10
Buffalo	0.10
Swine	0.45

Source: IPCC, 1996

Table 4.4 Methane Conversion Factors for Different Manure Management Systems and the Proportion of Manure Handling Systems Used for Various Animals

Manure Management System	MCF[1] (percent)	MS[2] (percent)			
		Dairy cattle	Non-dairy cattle	Buffalo	Swine
Lagoon	90	0	0	0	5
Liquid /Slurry	65	10	0	0	25
Solid	2	45	10	10	25
Dry Lot	5	25	30	30	30
Pasture/Range	2	20	60	60	0
Daily Spread	1	0	0	0	0
Digester	10	0	0	0	5
Burned for Fuel	10	0	0	0	0
Others	1	0	0	0	10
Total	**100**	**100**	**100**	**100**	**100**

Notes: [1] IPCC, 1996
[2] Personal communication

Table 4.5 Methane Conversion Factors (MCF x MS) for the Manure of Various Animals

Manure Management System	MCF (percent)	MS (percent)				MS x MCF			
		Dairy Cattle	Non-dairy Cattle	Buffalo	Swine	Daily Cattle	Non-dairy Cattle	Buffalo	Swine
Lagoon	90	0	0	0	5	0.0000	0.0000	0.0000	0.0450
Liquid/Slurry	65	10	0	0	25	0.0650	0.0000	0.0000	0.1625
Solid	2	45	10	10	25	0.0090	0.0020	0.0020	0.0050
Dry Lot	5	25	30	30	30	0.0125	0.0150	0.0150	0.0150
Pasture/Range	2	20	60	60	0	0.0040	0.0120	0.0120	0.0000
Daily Spread	1	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Digester	10	0	0	0	5	0.0000	0.0000	0.0000	0.0050
Burn	10	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Others	1	0	0	0	10	0.0000	0.0000	0.0000	0.0010
Total						**0.0905**	**0.0290**	**0.0290**	**0.2335**

Table 4.6 Nitrous Oxide Emission Factors (EF) and Percentage of Different Manure Management Systems used for Various Animals

Manure Management System	EF (kg N_2O)	Animal (percent)				
		Dairy Cattle[1]	Non-dairy Cattle[1]	Buffalo[1]	Swine[1]	Poultry[2]
Lagoon	0.001	0	0	0	5	1
Liquid/Slurry	0.001	10	0	0	25	2
Solid	0.02	45	10	10	25	0
Dry Lot	0.02	25	30	30	30	0
Pasture/Range	0.02	20	60	60	0	44
Daily Spread	0.0	0	0	0	0	0
Digester	0.0	0	0	0	5	1
Burn	0.0	0	0	0	0	0
Others	0.005	0	0	0	10	52

Notes: [1] Personal communication
[2] IPCC, 1996

Table 4.7 Estimated Nitrogen Excretion from Animals (Nex_t) and Waste Management (Nex_{awms})

Animals	Nex_t	N excretion (kg/yr)									Nex_{awms} (N kg/yr)
		Lagoon	Liquid	Solid	Dry Lot	Pasture	Daily spread	Digester	Burn	Others	
Dairy cattle	60	0	1,595,238	7,178,571	3,988,095	3,190,476	0	0	0	0	15,952,380
Non-dairy cattle	40	0	0	29,485,908	88,457,724	176,915,448	0	0	0	0	294,859,080
Buffalo	40	0	0	16,899,164	50,697,492	101,394,984	0	0	0	0	168,991,640
Swine	16	6,783,520	33,917,600	33,917,600	40,701,120	0	0	6,783,520	0	13,567,040	135,670,400
Poultry	0.6	910,854	1,821,707	0	0	40,077,553	0	910,854	0	47,364,381	91,085,348

4.4 RESULTS

The population of major economic animals in Thailand in 1994 was 265,873 for dairy cattle; 7,371,477 for non-dairy cattle; 4,224,791 for buffalo; 8,479,400 for swine; and 151,808,913 for poultry. The population of non-dairy cattle and buffalo was much greater than other ruminants. Although relatively small in number, however, the population of dairy cattle in the country has been increasing at a rapid pace. According to the Division of Agricultural Research (1995), the population of dairy cattle increased at the rate of about 22 percent per annum during the 6th National Economic and Social Development Plan (1988-1991).

Estimates of methane production from the microbial digestion of feed from all livestock during the base year, 1994, are shown on Table 4.8. Dairy cattle, non-dairy cattle, buffalo and swine produced an estimated 17.897 349.163, 249.748 and 12.719 Gg of methane, respectively, from the enteric fermentation of digested feed. Total methane emissions from the microbial fermentation of feed from all animal types in 1994 was 629.526 Gg.

During the same year, an additional 2.658, 13.555, 9.716 and 109.948 Gg of methane and 0.454, 9.270, 5.311 and 2.516 Gg of nitrous oxide were found to be released from the management of wastes produced by the four major economic animals, respectively. Altogether, 125.813 Gg of methane and 19.192 Gg of nitrous oxide were emitted from the manure of all livestock. By type of animals, non-dairy cattle and buffalo were found to produce about 95.1 percent of total methane emissions from enteric fermentation (Figure 4.1) and 81.2 percent of nitrous oxide emissions from the manure management systems (Figure 4.2), while the swine population was responsible for about 87.4 percent of the methane emissions from all livestock manure (Figure 4.3).

Table 4.8 Methane and Nitrous Oxide Emission from Livestock, 1994

Animals	Number	Enteric methane (Gg/yr)	Fecal methane (Gg/yr)	Nitrous oxide (Gg/yr)
Ruminants:				
Dairy cattle:	**265,873**	**17.897**	**2.658**	**0.454**
Cow	138,254	12.509	1.824	
Female, 0-1 yr	39,881	0.988	0.144	
Female, 1-2 yr	37,222	1.741	0.273	
Heifer, > 2 yr	50, 516	2.658	0.417	
Non-dairy cattle:	**7,371,477**	**349.163**	**13.555**	**9.270**
Female:	5,012,604			
Cow	2,506,302	130.103	4.910	
Female, 0-1 yr	852,143	18.433	0.712	
Female, 1-2 yr	852,143	38.860	1.537	
Female, > 2 yr	802,017	37.663	1.489	
Male:	2,358.873			
Bull	1,179,436			
Male, 0-1 yr	401,008	12.128	0.480	
Male, 1-2 yr	401,008	21.558	0.852	
Male, > 2 yr	377,420	23.073	0.912	
Buffalo:	**4,224,791**	**249.748**	**9.716**	**5.311**
Female:	2,661,618			
Mature	1,330,809	81.976	3.094	
Female, 0-1 yr	449,475	11.315	0.515	
Female, 1-2 yr	452,475	24.489	0.968	
Female, > 2 yr	425,859	24.122	0.954	
Male:	1,563,173			
Mature	781,586	61.483	2.431	
Male, 0-1 yr	265,739	7.467	0.295	
Male, 1-2 yr	265,739	17.377	0.687	
Male, > 2 yr	250,108	19.519	0.772	
Non-ruminants:				
Swine	**8,479,400**	**12.719**	**109.948**	**2.516**
Poultry	**151,808,913**	**0.000**	**3.492**	**1.641**
Total		**629.526**	**139.369**	**19.192**

Source: Department of Livestock Development (1997)

Figure 4.1 Contribution of Certain Livestock on Enteric Methane Emission, 1994

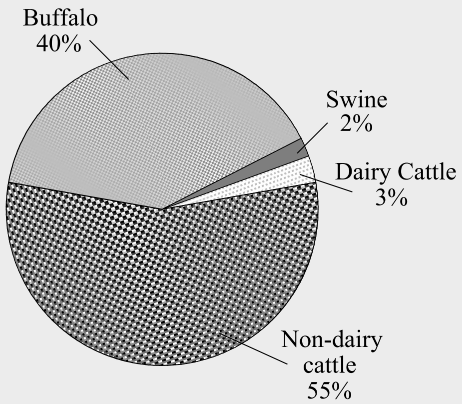


Figure 4.2 Contribution of Certain Livestock on Manure Nitrous Oxide Emission, 1994

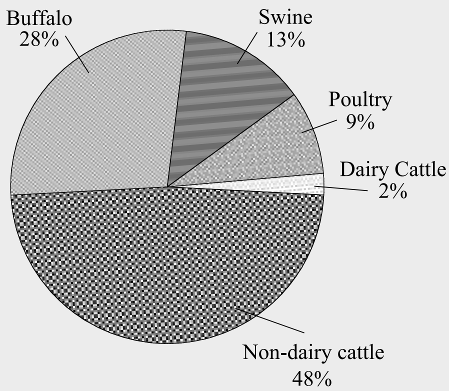
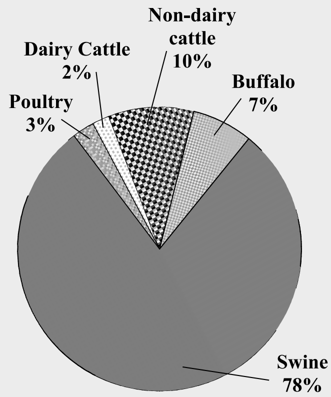


Figure 4.3 Contribution of Certain Livestock on Manure Methane Emission, 1994



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APPENDIX

Strategies for GHG Emission Mitigation from Livestock

Anticipated Trends in GHG Emissions from Livestock

Parallel to the growth in numbers of most livestock, methane and nitrous oxide emissions from animals in Thailand are expected to increase. Based on the historical trend, it was projected that Methane and nitrous oxide emissions would increase from 687 and 19 Gg in 1994 to 691 and 22 Gg in 2020, with the slight drops in 2000. Unless the composition of the animal population changes, it is anticipated that non-dairy cattle and buffalo would continue to account for most of enteric methane and nitrous oxide from manure, while swine production would be responsible for most of the methane released from all livestock manure. To be effective, emission reduction strategies must therefore be targeted at these specific groups of animals.

Strategies to Reduce Methane Emissions from Enteric Fermentation

Most ruminants in Thailand are raised under a system of smallholding. Under this system, the animals are generally provided with minimum input. Insufficient nutrient intake as well as nutrient imbalance lead to insufficient rumen fermentation.

The reports of McDowell (1997) show that improving the nutrient intake of ruminants could have beneficial impacts on the animals. For example, 37 percent improvement in calving percentage were observed when Thai village cattle received only mineral supplements. Therefore, an improvement in feed utilization efficiency could be considered as a means to reduce GHG emissions, particularly from large ruminants.

To achieve this objective, the following national feeding improvement plans for ruminants are recommended:

1. Mineral supplements to meet the minimum local requirements of animals should be formulated and provided for use by the farmers.

2. Supplementing poor quality roughage with urea-molasses, legumes and/or low-cost agricultural by-products should be encouraged wherever and whenever economically and socially feasible.

3. Chemical treatment of low quality roughage, particularly with urea solution should be employed wherever possible. The treatment technique has been successfully utilized to improve the digestibility and to increase the non-protein nitrogen content of fibrous feeds.

4. Wider use of pasture and forage conservation for dry season feeding, particularly in the case of dairy cattle, should be promoted.

With a proper nationwide extension program, it is anticipated that the digestibility of feeds for various ruminants will gradually increase to about 65 percent or over by the year 2020. Higher feed utilization efficiency will eventually reduce enteric methane emission through improved rumen fermentation and, at the same time, lower the volume of fecal excretion in the animals. According to IPCC (1996), a 5 percent improvement in the digestibility of feed for ruminants could eventually lead to a 10 percent reduction in enteric methane emission. At this level of feed digestibility improvement, a further decline of 22 percent in fecal methane could be observed, as fecal outputs from the animals are reduced.

Another approach to mitigating methane production from rumen fermentation involves the use of ionophore, particularly monensic acid, in ruminants. When used as an additive in feed, monensin is reported to provide a general increase in annual productivity. The ionophore enhances the molar proportion of propionic acid and, thereby, causes a consequent reduction in methane production in the rumen. Studies by Dinius, *et al*. (1976) and Thornton, *et al*. (1976) showed a decline of 40.5 percent and 16.6 percent in methane production, respectively. The use of monensin in enteric methane emission mitigation will be cost effective through its enhancing effect towards the animal's feed conversion efficiency. Table A4.1 illustrates the feed digestibility improvement target from 1995 to 2020 through the use of ionophore as a feed additive for large ruminant animals.

Strategies to Reduce Fecal Methane Emissions

Since over 85 percent of fecal methane in 1994 were from swine, emphasis must be given to improving the waste management system that is currently in place. Zoning regulations for swine farming, particularly those for small and medium-sized farms, should be introduced. These areas should be furnished with central wastewater treatment facilities. Similar wastewater treatment systems should be enforced for large scale swine production operation elsewhere in the country. Wherever possible, the methane gas produced must be harvested as fuel for heating, electricity or other energy purposes. The schedule for manure management modification from swine production activities is illustrated on Table A4.2.

Table A4.1 Percentage of Large Ruminant Population Scheduled for Feed Improvement and Feed Additive Extension Program, 1995-2020.

Animals	Year					
	1995	2000	2005	2010	2015	2020
Dairy Cattle	0	5	10	20	30	40
Non-dairy cattle and buffalo	0	5	10	15	20	25

Table A4.2 Schedule of Manure System Modification for Fecal Methane and Nitrous Oxide Emission Mitigation from Swine, 1995-2020

Manure system	Year					
	1995	2000	2005	2010	2015	2020
Lagoon	5	3	0	0	0	0
Liquid (Slurry)	25	20	15	10	5	5
Solid	25	25	25	25	25	25
Dry Lot	30	25	20	15	10	5
Pasture (Range)	0	0	0	0	0	0
Dairy Spread	0	0	0	0	0	0
Digester	5	10	15	20	25	30
Fuel Combustion	0	0	0	0	0	0
Others	10	17	25	30	35	35

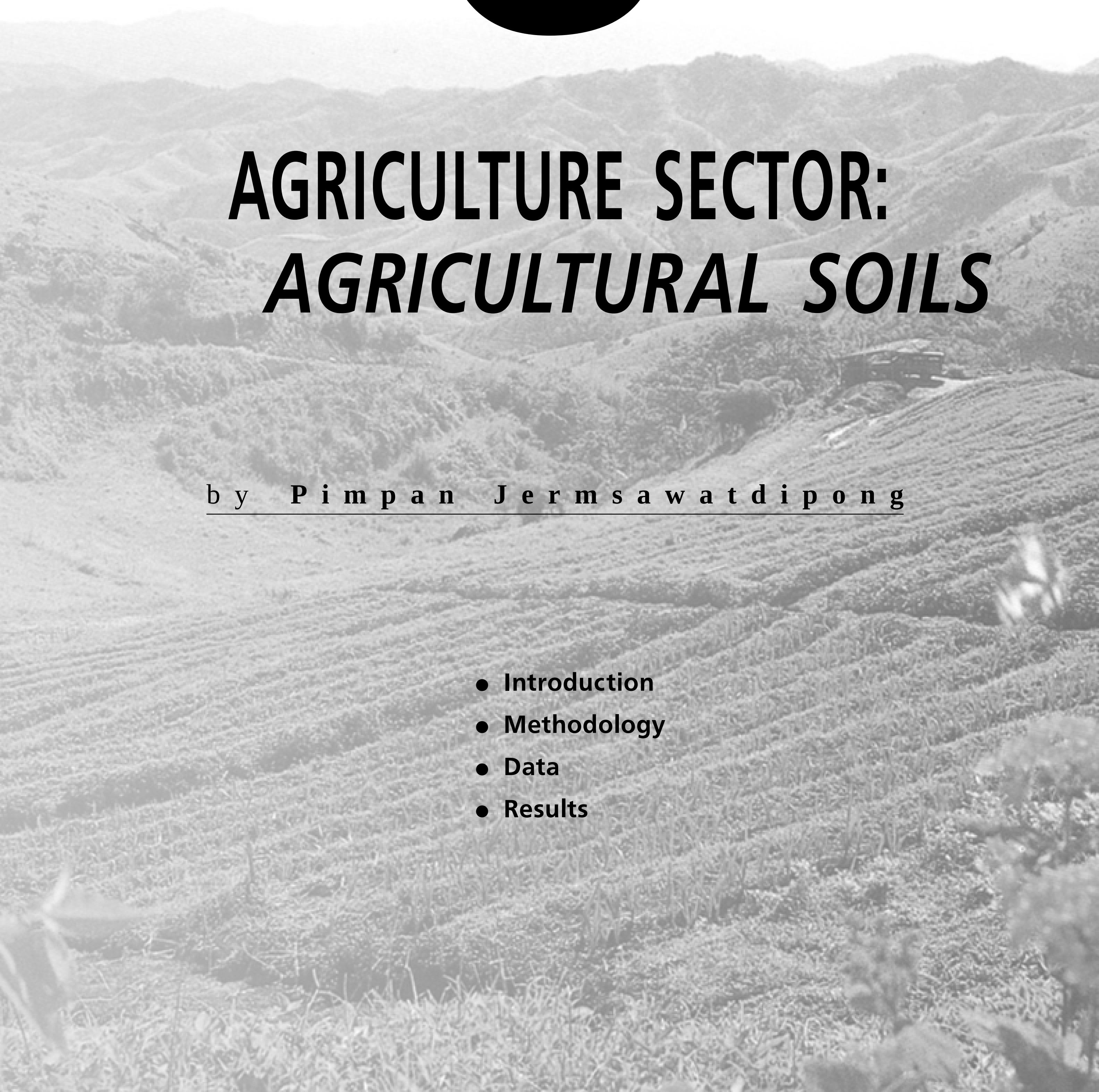
CHAPTER

5

AGRICULTURE SECTOR: *AGRICULTURAL SOILS*

by **Pimpan Jermsawatdipong**

- **Introduction**
- **Methodology**
- **Data**
- **Results**



5.1 INTRODUCTION

The most important source of N_2O emission from agricultural soils in Thailand is the utilization of synthetic nitrogen fertilizers, both from the fractions volatilized directly from cultivated soils and from the indirect leachate contamination of groundwater. The amount of fertilizers used in Thailand has increased significantly in the past few years. Between 1981-1990, fertilizer consumption grew by an average of 13.4 percent per year, much higher than the average global rate of 4.1 percent per year for developing countries and 1.3 percent for developed countries. By type of fertilizers, the annual increase in demand for nitrogen fertilizers was 18.3 percent, while those for phosphorus and potassium fertilizers were 10 percent and 14.1 percent, respectively. As demand for food increases, the need for fertilizers will multiply.

This study provides preliminary estimates of N_2O emissions from agricultural soils in Thailand based on the methodology proposed in the 1996 IPCC Guidelines (IPCC, 1997). Country conversion factors were employed in some of the calculations in order to compare with IPCC's default factors. The base year for this estimation is 1994.

This study presents estimates of N_2O emitted from agricultural soils using agricultural statistics for the country (Agricultural Statistics of Thailand, 1994/95) and the 1996 IPCC methodology. The three major sources of soil nitrogen which enhance N_2O emissions are the application of nitrogenous fertilizers into the soil (direct source), grazing animals, and the biogenic formation through atmospheric deposition, leached water and sewage treatment (indirect source).

5.2 METHODOLOGY

Sources of N_2O Emission

Based on the revised 1996 IPCC Guidelines (IPCC, 1997), total N_2O emission consists of:

$$\textbf{Total } \mathbf{N_2O} = \mathbf{N_2O_{DIRECT} + N_2O_{ANIMALS} + N_2O_{INDIRECT}}$$

where:

N_2O_{DIRECT} is N_2O emission from various sources of nitrogen put directly into soils per year. These nitrogen sources include: (1) synthetic nitrogen fertilizer (F_{SN}), (2) animal waste or manure (F_{AW}), (3) symbiotic N-fixation (F_{BN}), (4) crop residues (F_{CR}), (5) compost (F_{COM}), and (5) cultivation of organic soils (F_{OS}).

$N_2O_{ANIMALS}$ is N_2O emission from grazing animals per year. Other emissions from animals such as those from the enteric fermentation of feed from ruminant animals and animal waste management are not included in this estimate.

$N_2O_{INDIRECT}$ is N_2O emission indirectly produced per year from various sources of nitrogen input. These sources consist of: (1) biogenic formation of N_2O from atmospheric deposition of NO_x and NH_3 produced from fertilized soils and surface water and (2) biogenic formation of N_2O from leached/runoff water. Another source of indirect N_2O emission, i.e., biogenic formation of N_2O from sewage treatment, is estimated in the Waste section.

Calculation Method

Equation 1.

$$\mathbf{N_2O_{DIRECT} = [(F_{SN} + F_{AW} + F_{BN} + F_{CR} + F_{COM}) \times EF_1] + (F_{OS} \times EF_2)}$$

where:

EF_1 = emission factor for direct soil emissions (kg N_2O-N/kg N input) (Table 4-18 in 1996 IPCC Guidelines)

EF_2 = emission factor for organic soil mineralisation (kg N_2O-N/ha/yr) (Table 4-18 in 1996 IPCC Guidelines)

F_{SN} = synthetic nitrogen fertilizer applied in country (kg N/yr)

F_{AW} = animal manure nitrogen used as fertilizer (kg N/yr)

F_{BN} = N fixed by N-fixing crops in country (kg N/yr)

F_{CR} = N in crop residues returned to soil in country (kg N/yr)

F_{COM} = N in compost applied to soil in country (kg N/yr)

F_{OS} = area of cultivated organic soil within country (ha)

Equation 2.

$$N_2O_{ANIMALS} = \Sigma [N_{(T)} \times Nex_{(T)} \times Frac_{GRAZ(T)} \times EF_3]$$

where:

$N_{(T)}$ = animal numbers of type T in the country

$Nex_{(T)}$ = N excretion of animal of type T in the country (kg N/animal/yr) (Table 4-20 in 1996 IPCC Guidelines)

$Frac_{GRAZ(T)}$ = fraction of $Nex_{(T)}$ that is released in one of the different grazing animal of type T in the country (Table 4-21 in 1996 IPCC Guidelines)

EF_3 = N_2O emission factor for animal waste excreted in pastures (0.02 kg N_2O-N/kg of Nex)

Equation 3.

$$N_2O_{INDIRECT} = N_2O_{(G)} + N_2O_{(L)}$$

where:

$N_2O_{(G)}$ = N_2O emission from atmospheric deposition of NO_x and NH_3

$N_2O_{(L)}$ = N_2O emission from nitrogen leaching and runoff

5.3 DATA

Synthetic Fertilizer

Nitrogen fertilizer consumption in 1994 varied by crop types. Rice production utilized about 43 percent of the country's total consumption, while other crops each accounted for about 17-20 percent. Nitrous oxide released from rice cultivation in Thailand was assumed to be minimal because fertilizer was normally applied to irrigated areas which are under continuous flooding. Nitrous oxide emission from paddy fields only occurs during drainage period. Hence, only nitrogen fertilizers used for other crops were the main sources of nitrous oxide emissions. The fraction of nitrogen fertilizer that is volatilized as NH_3 and NO_x, equivalent to 0.1 kg NH_3-N+NO_x-N/kg of synthetic fertilizer applied, was accounted for in the loss of soil N (IPCC, 1997).

The contributions of nitrogen compounds from synthetic fertilizer application are presented on Table 5.1. The fraction of nitrogen that enters into the soil (F_{SN}) and which is lost as NH_3 and NO_x during the application of nitrogenous fertilizers is estimated at 348,715 and 38,746 tonnes in 1994, respectively.

Animal Waste or Manure

Organic nitrogen fertilizer applied to soils from animal manure was quantified based on animal population (see Table 5.2), and waste management. The nitrogen excretion (Nex) for each type of animal was determined using the IPCC default values given on Table 4-20 of the 1996 IPCC Guidelines (IPCC,1997) for all type of manure management system excluding pasture/range and percentages of different manure management system used for various animals presented in Table 4.7 in the livestock sector in Chapter 4 above. These amounts were then

Table 5.1 Nitrogen Produced From Synthetic Nitrogen Fertilizer Application, 1994

Synthetic nitrogen fertilizer application	NFERT N fertilizer application (tonnes/yr)	Loss as NH_3+NO_x (tonnes/yr)	FSN Net soil N input (tonnes/yr)
Field crops	116,291	11,629	104,662
Fruit trees	135,571	13,557	122,014
Vegetables & Ornamental Plants	135,600	13,560	122,040
Total	**387,462**	**38,746**	**348,715**

Table 5.2 Animal Population of Thailand, 1994

Type of Animal	Number of Heads
Dairy cattle	265,873
Non-dairy cattle	7,371,477
Buffaloes	4,224,791
Swine	8,479,400
Poultry	151,808,913

Source: Department of Livestock Development (1997)

Table 5.3 Nitrogen Entering Agricultural Soils from Animal Manure, Estimated using Revised IPCC Methodology

Livestock Type	Total Nitrogen Excretion Nex (kg N/yr)	Fraction of Nitrogen Burned for Fuel/1 (fraction)	Fraction of Nitrogen Excreted During Grazing/2 (fraction)	Fraction of Nitrogen Excreted Emitted as NO_X and NH_3/3 (fraction)	Manure Nitrogen Used (corrected for NO_X and NH_3 emissions), F_{AW} (kg N/yr)
Dairy Cattle	15,950,220	0	0.2	0.2	9,570,132
Non-dairy Cattle	294,859,080	0	0.6	0.2	58,971,816
Buffalo	168,991,640	0	0.6	0.2	33,798,328
Swine	135,670,400	0	0	0.2	108,536,320
Poultry	91,085,348	0	0.44	0.2	32,790,725
		TOTAL			**243,667,321**

Sources: IPCC Guidelines 1996 (1997)
/1 Table 4-21 (Asia and Far East Region)
/2 Table 4-21 (Asia and Far East Region)
/3 Table 4-19 (FracGASM)

corrected for volatilized loss as NH_3 and NO_x and for manure used as fuel (see Table 5.3). The fraction of nitrogen excretions used as fuel and produced during grazing are given on Tables 4-19 and 4-21, respectively, of the 1996 IPCC Guidelines.

Crop Residues

Nitrogen that entered agricultural soils from crop residues data was estimated based on the annual edible portion of crop production of both non-nitrogen fixing and nitrogen-fixing crops which was then doubled to estimate crop biomass. The fraction of crop residues that was burned ($Frac_{BURN}$) and removed from the fields as crop ($Frac_R$) which were assumed at 0.25 and 0.45 kg N per kg crop-N, respectively (Table 4-19 of 1996 IPCC Guidelines), was excluded from total amount of crop residues produced. The proportion of N in both non-N fixing ($Frac_{NCRO}$) and N fixing crops ($Frac_{NCRBF}$) were 0.015 and 0.03 kg N per kg dry biomass.

$$F_{CR} = 2 \times [Crop_O \times Frac_{NCRO} + Crop_{BF} \times Frac_{NCRBF}) \times (1-Frac_R) \times (1-Frac_{BURN})$$

where

$Crop_O$ = production of all other crops in country (kg dry biomass/yr)

$Crop_{BF}$ = seed yield of pulses + soybean in country (kg dry biomass/yr)

Calculated net N entering soils (F_{CR}) for each crop type are presented on Table 5.4. Comparison was made between IPCC estimation method of net soil N input and those estimation using country conversion factors and nitrogen content of crop biomass (see Table 5.5).

Table 5.4 Nitrogen Entering Agricultural Soils from Crop Residues, Estimated using IPCC Methodology

Type of Crop Residues	Edible Crop Yield[1] (tonnes/yr)	Crop N (tonnes/yr)	FCR Net soil N input (tonnes/yr)
Non-N fixing crops:			
Rice	21,110,714	316,661	261,245
Maize stalk	3,965,339	59,480	49,071
Cane leaves and tops	50,597,339	758,960	626,142
Cassava stalk	19,091,347	286,370	236,255
Sorghum stalk	228,121	3,422	2,823
N-fixing crops:			
Peanut stalk	150,329	4,509.87	3,721
Soybean stalk	527,580	15,827.40	13,058
Mungbean stalk	255,506	7,665.18	6,324
Total	**95,926,275**	**1,445,230**	**1,198,639**

N.B. Crop N was estimated based on crop yield and default nitrogen content as given in the 1996 IPCC Guidelines

Source: /1 Agricultural Statistics of Thailand (1996).

Table 5.5 Nitrogen Entering Agricultural Soils, Estimated using Country Information

Type of Crop Residues	Planted Area[1] (ha)	Crop Residues/ Planted Area (tonnes/ha)	Nitrogen Content[4] (kg N/kg dry) Biomass	Crop N (tonnes N/yr)	Fraction of Crop Residue Removed from Field, (fraction)	Fraction of Crop Residue Burned (fraction)	N input from Crop residues F_{CR} (kgN/yr)
Non-N-fixing crops:							
Rice straw:							
North region	1,800,176	3.125[2]	0.0057	32,066	0.45	0.25	13,227,076
Northeast region	4,370,066	1.875[2]	0.0057	46,705	0.45	0.25	19,265,847
Central region	1,871,492	4.375[2]	0.0057	46,670	0.45	0.25	19,251,517
South region	440,697	3.125[2]	0.0057	7,850	0.45	0.25	3,238,091
Maize stalk	1,351,349	3.125[3]	0.0080	33,784	0.45	0.25	13,935,789
Cane	922,705	1.688[3]	0.0049	7,632	0.45	0.25	3,148,148
Cassava stalk	1,382,695	4.375[3]	0.0123	74,406	0.45	0.25	30,692,593
Sorghum stalk	167,238	4.375[3]	0.0080	5,853	0.45	0.25	2,414,500
N-fixing crops:							
Peanut stalk	100,184	3.750[3]	0.0120	4,508	0.45	0.25	1,859,657
Soybean stalk	395,399	3.125[3]	0.0136	16,804	0.45	0.25	6,931,834
Mungbean stalk	334,996	1.875[3]	0.0104	6,532	0.45	0.25	2,694,625
Total	**13,136,998**			**282,811**			**113,965,051**

N.B. Crop N was estimated using planted area and country conversion factors.

Sources: /1 Agricultural Statistics 1996

/2 Tanyadee, 1986

/3 Piriyapan, V., 1982

/4 Vacharotayan, S. and A. Pintukanok, 1985

Biological Nitrogen Fixation

Nitrogen-fixing crops commonly grown in Thailand are soybean, mungbean and peanuts (Agricultural Statistics, 1996). The symbiotic nitrogen fixation was estimated by using annual crop production data and the fraction of nitrogen in nitrogen-fixing crops, which is assumed at 0.03 kg N per kg dry biomass (Table 4-19 of the 1996 IPCC Guidelines). The results of soil N derived from N-fixing crops (F_{BN}) are shown on Table 5.6 in comparison with the amount determined using country conversion factors and crop residue nitrogen content (see Table 5.5).

$$F_{BN} = 2 \times Crop_{BF} \times Frac_{NCRBF}$$

Compost

Recently, there has been much interest in the use of organic waste and farm residues for improving soil fertility. The Ministry of Agriculture and Cooperatives has advised farmers to produce their own compost using crop residues and animal manure. The Department of Land Development has been conducting a national project to promote the techniques for making compost at both farm and industrial levels. The Bangkok Metropolitan Administration is also now producing compost from municipal wastes. The nitrogen content of these composts varies widely depending on the materials used. City composts are richer in nitrogen than those made from farm residues. But the contribution of compost to soil N (F_{COM}) is relatively small as shown on Table 5.7.

Cultivation of Organic Soils

Most of the organic soils in Thailand are located mainly in peat swamp forest areas in the southern region. The peat swamp forests have not been utilized until recently; they had been exploited mainly for large scale logging operations. Also, the government has administered reclamation projects by putting open ditches for drainage and by clear-cutting the forest. Such large-scale disturbances irreversibly alter the forest ecosystem, which is a valuable CH_4 and N_2O sink. The destruction of swamp forests may result in increased CO_2 and CH_4 emissions to the atmosphere particularly in the wet season, and may be a weak source of CH_4 and NO_2 in the dry season (Yoshida, *et al.*, 1995). The land area of peat soils utilized for agriculture is not yet available.

Table 5.6 Nitrogen Input into Soils from Nitrogen-fixing Crops Estimated using IPCC Methodology and Country Information (tonnes/yr)

Crop Type	Edible Crop Yield/1	Fraction of N In N-fixing crops	FBN Biological N fixation	
			IPCC	Local/2
Soybeans	527,580	15,827	31,655	4,508
Mungbeans	255,506	7,665	15,330	16,804
Groundnuts	150,329	4,510	9,020	6,532
Total	**933,415**	**28,002**	**56,005**	**27,845**

Source: /1 Agricultural Statistics of Thailand (1996)
/2 see Table 5.5

Table 5.7 Nitrogen Entering into Agricultural Soils from Compost

Producer	Type of Compost	Production/1 (tonnes/yr)	N content/2 (percent)	Loss as NH_3 + NO_x (tonnes/yr)	FCOM N input, (tonnes/yr)
Bangkok Metropolitan Administration	City compost	21,600	2.58	56	502
Private Sector	Compost	207,084	1.36	282	2,535
Ministry of Agriculture and cooperatives	Farm residue compost	124,105	1.00	124	1,117
Total		**352,789**		**461**	**4,153**

Sources: /1 Limthong, P., 1993
/2 Vacharotayan, S. and A. Pintukanok, 1985

Grazing Animals

Nitrous oxide derived from deposition of animal urine and dung of grazing animals was determined using equation 2. Table 5.8 shows nitrogen excretion from grazing animals.

Atmospheric Deposition of NH_3 and NO_x

Synthetic fertilizer and animal manure applied to soils may be lost shortly by volatilization after incorporation as NH_3 and NO_x and then transformed to N_2O. The default values for NH_3 and NO_x volatilization from synthetic fertilizer and animal manure are 0.1 and 0.2 kg N per kg fertilizer, respectively. These volatile nitrogen compounds enhance biogenic N_2O formation. The emission factor of this transformation is 0.01 kg N_2O-N per kg NH_3-N+NO_x-N deposition (IPCC, 1997). Estimated nitrous oxide emission indirectly from synthetic fertilizer and animal manure are presented in Table 5.9.

Leaching and Runoff Nitrogen Compounds

A fraction of the nitrogen applied to the soil as synthetic fertilizer and animal manure is leached through the percolation of water or transported via surface runoff water. The leached/runoff N enters the groundwater, riparian areas and wetlands, rivers, and eventually the coastal areas. The default conversion factor for leaching loss (N_{LEACH}) used is **0.2** kg per kg applied N (personal communication), **0.1 less than that provided by IPCC Guideline**. The fraction of N_2O produced from groundwater and agricultural drainage water is 0.015 kg per kg N_{LEACH}, while those during river transport and coastal marine are 0.0075 kg per kg N_{LEACH} and 0.0025 kg per kg N_{LEACH}, respectively. Table 5.10 shows nitrous oxide emission from the fraction of N that leached/runoff.

Table 5.8 Nitrogen Excretion from Grazing Animal

Livestock Type	Number of Animals N_T (head)	Nitrogen Excretion $Nex_{(T)}$ (Kg/head/yr)	Fraction of Manure Nitrogen per AWMS ($Frac_{GRAZ(T)}$ [/1])	Nitrogen Excretion, Nex (kg/N/yr)
Dairy Cattle	265,837	60	0.2	3,190,044
Non-dairy Cattle	7,371,477	40	0.6	176,915,448
Buffalo	4,224,791	40	0.6	101,394,984
Swine	84,794	16	0	0
Poultry	151,808,913	0.6	0.44	40,077,553
			Total	**321,578,029**

Source : [/1] see Table 4.7 in Livestock sector

Table 5.9 Nitrous Oxide Emission Derived from NH_3 and NO_x Volatilization from Synthetic Fertilizer and Animal Manure

Source	Amount of Nitrogen Input (kg N/yr)	Fraction of Applied N that Volatilizes (fraction)	Amount of N that loss as NH_3+NO_x (kg N/yr)	Emission factor (kg N_2O-N/kg N)	Total N_2O emission (Gg N_2O/yr)
Synthetic fertilizer	387,461,500	0.1	38,746,150	0.01	0.61
N excretion from animal manure	647,039,428	0.2	129,407,886	0.01	2.03
Total	**1,034,500,928**		**168,154,036**		**2.64**

Table 5.10 Estimated Nitrous Oxide Derived from Leached/Runoff Nitrogen

Source	Amount of nitrogen Input (kg N/yr)	Fraction of N That Leached (fraction)	Nitrous Oxide Emissions Factor from Groundwater $EF5_{-g}$	Nitrous Oxide Emissions Factor from Rivers $EF5_{-r}$	Nitrous Oxide Emissions Factor from Coastal Marine Areas $EF5_{-e}$	Total Nitrous Oxide Emissions from Leaching (Gg N_2O/yr)
Synthetic fertilizer	387,461,500	0.2	0.015	0.0075	0.0025	4.57
N excretion from animal manure	647,039,428	0.2	0.015	0.0075	0.0025	7.63
Total	**1,034,500,928**					**12.19**

5.4 RESULTS

Direct Emission

Direct emission of N_2O was estimated using Equation 1 above and the IPCC default emission factor (EF_1 = 0.0125 kg N_2O-N per kg N). The results shown on Table 5.11 indicate that about half of direct emission are contributed from synthetic fertilizer, while the incorporations of animal manure and crop residues into the soil determined using country data are also important sources. The use of country conversion factors resulted in much lower N_2O emission (less than half of total emissions), particularly those emanating from crop residues. Emission factor of nitrogen oxide from synthetic fertilizer measured directly from 4 typical maize cultivation areas in Thailand was 0.005 (0.0025 to 0.0077) kg N_2O per kg of applied nitrogen fertilizer (Chairoj, P., S. Launmanee and T. Watanabe. 1998), which was less than half of the default emission factors used in this estimation. However, field measurement of soil nitrogen transformation and transport processes are needed locally under different soil and water management system.

N_2O emission from grazing animals

Nitrous oxide emissions from grazing animals estimated from total nitrogen excreted (Nex) as shown in Table 5.8 and default N_2O emission factor of 0.02 kg N_2O-N per kg of N excreted was 10.11 Gg N_2O in 1994.

Indirect Emission of N_2O

Nitrous oxide emission from indirect sources; atmospheric deposition of NH_3 and NO_x and leaching/ runoff of soil nitrogen are presented in Table 5.12. Large amount of emission was contributed from leaching/runoff of nitrogen in agricultural soils and particularly originated from animal manures.

Total Country N_2O Emission

Nitrous oxide emissions in 1994, estimated from various sources are summarized on Table 5.13. The direct source contributed the highest amount of N_2O emission, almost 50 percent derived from utilization of synthetic fertilizer. Animal waste applied to soils as manure from different waste management system and grazing animals dominated emission of N_2O.

Table 5.11 Nitrous Oxide Emissions from Direct Sources

Type of N input to soil	Amount of N Input (kg N/yr)	Factor for Direct Emissions EF_1 (kg N_2O-N/kg N)	Direct Soil Emissions (Gg N_2O-N/yr)	Total Direct Emissions of N_2O (Gg)
Synthetic fertiliser (FSN)	348,715,350	0.0125	4.36	6.85
Animal waste (FAW)	243,667,321	0.0125	3.05	4.79
N-fixing crops (FBN)	27,845,129	0.0125	0.35	0.55
Crop residue (FCR)	116,659,677	0.0125	1.46	2.29
Compost (FCO)	4,153,205	0.0125	0.05	0.08
		Total	**9.26**	**14.56**

Table 5.12 Indirect N_2O Emission from Atmospheric Deposition of Volatile Synthetic Nitrogen Fertilizer and Animal Manure and Leached Soil Nitrogen

Source	Total Nitrous Oxide Emissions, (Gg N_2O/yr)		
	Atmospheric Deposition	Leaching	Total
Synthetic fertilizer	0.61	3.04	3.65
N excretion from animal manure	2.03	5.08	7.12
Total	**2.64**	**8.13**	**10.77**

Table 5.13 Total Emission of N_2O from Agricultural Soils, 1994

Source of N_2O emission	Direct sources	Grazing animals	Indirect sources	Total N_2O Emissions
Synthetic fertilizer	6.85		3.65	10.50
Animals	4.79	10.11	7.12	22.01
Crops	2.92			2.92
Total	**14.56**	**10.11**	**10.77**	**35.43**

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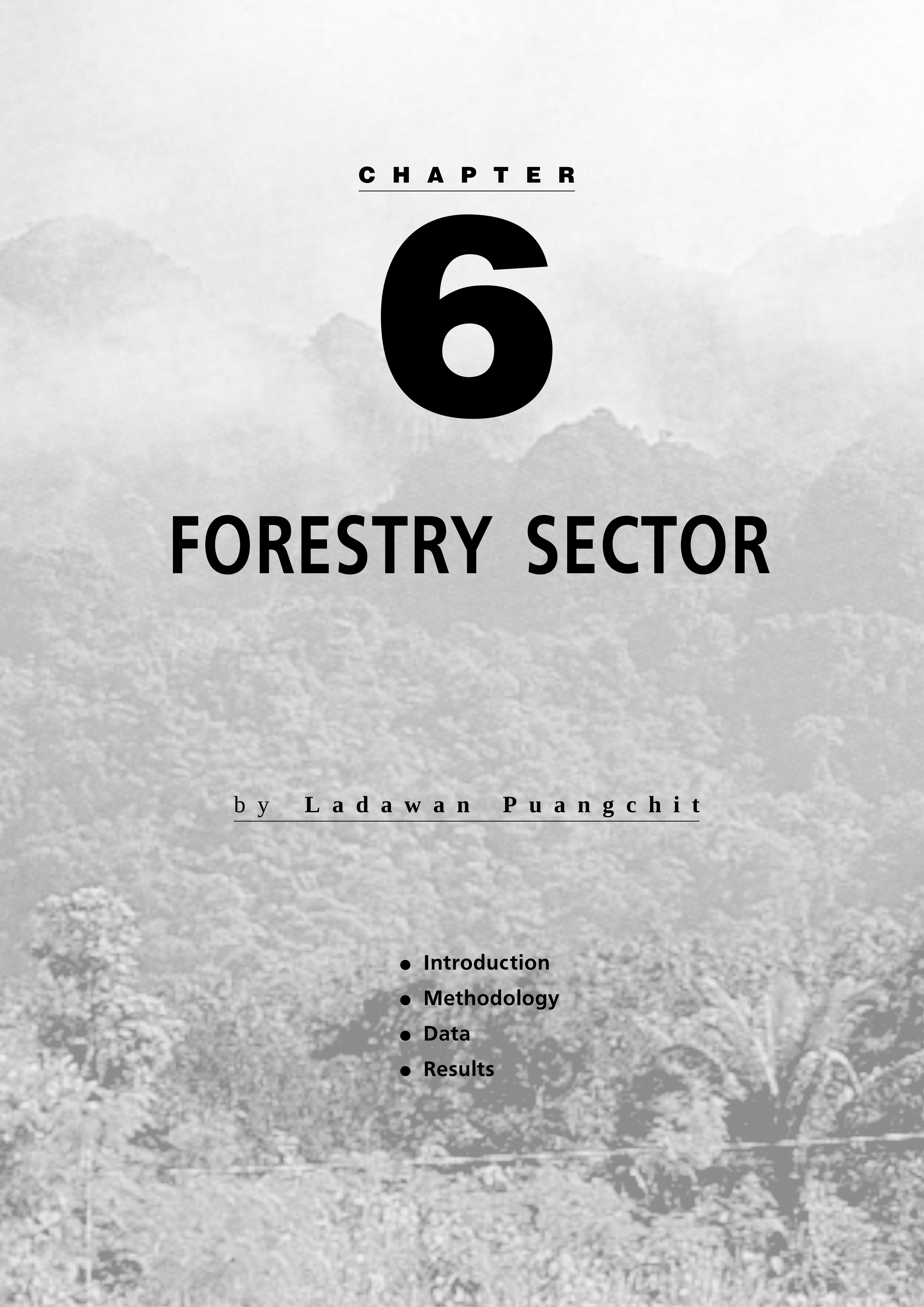

CHAPTER

6

FORESTRY SECTOR

by Ladawan Puangchit

- Introduction
- Methodology
- Data
- Results

6.1 INTRODUCTION

Forests act as both sink and source of carbon dioxide (CO_2). They act as sinks by withdrawing CO_2 from the atmosphere through the process of photosynthesis and by storing it in its woody biomass. Woody biomass can store carbon in plant tissue for periods of up to 200 years or more (Openshaw, 1996). On the other hand, CO_2 is produced when forested land is converted into other land uses, thereby exacerbating the rise in atmospheric carbon dioxide.

More than half of carbon stored in forests is lost to the atmosphere within the period of a year. Uncertainties in the estimates of carbon fluxes due to changes in tropical land use can arise from: the rate of change of forest areas, the use of converted forest land, and the biomass density of forests (Brown, *et al*., 1991). An attempt to improve the precision of the estimation was proposed at the Intergovernmental Panel on Climate Change (IPCC) meeting in Sao Paulo in 1990. The IPCC resolved to do this by creating a network of local scientists in tropical countries and by using a common framework to estimate the emissions and uptake of carbon for each country (Graca, *et al*., 1990).

The present study applies the methodology developed by IPCC to estimate carbon emission and sequestration from forests and land use changes in Thailand by using 1994 as a base year. The first carbon flux inventory was done in 1996 by using 1990 as a base year. In order to make the estimates more accurate and updated to local forest situations, modifications and specific assumptions have been made. The IPCC recommended default values were used when local data for the country were unavailable.

The present study estimates CO_2 emissions and sequestration primarily from activities related to forestry, i.e., the utilization of woody biomass and change in forested area. The procedure also accounts for the influence of past land use changes upon the contemporary CO_2 flux. Natural, undisturbed forests are considered to be in equilibrium, and are considered to be neither a source or sink of carbon. The fate and amount of subterraneous biomass is currently ignored in the calculation. The present study involves:

1. CO_2 emissions that result from the harvesting, deforestation and utilization of woody biomass;
2. CO_2 sequestration by reforestation, tree planting and the natural regeneration of abandoned land; and
3. Emissions of non-CO_2 trace gases such as methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and nitrogen oxide (NO_x) from biomass combustion.

Definitions

The following terms are commonly referred to in this report:

Biomass. The weight of living or dead organic matter in a tree, stand or forest above and below ground, in units such as living or dead weight, wet or dry weight, ash-free weight, etc.

Carbon sequestration. A process that involves the withdrawal of CO_2 from the atmosphere and its storage in plant biomass.

Dry matter (dm). Biomass that has dried to an oven dry state, which means that all loose water has been driven off, but the water that is part of the carbohydrate molecule and various volatile compounds still remain.

Degraded forest. Forests or grasslands that have been overutilised or poorly managed historically, and may have reduced biomass densities.

Organization of the Study

The IPCC Guidelines for calculating GHG emissions from land use change and forestry organize the estimation into four main categories, as follows:

Changes in forest and other woody biomass stocks. These include emission and sequestration of carbon through the following activities:

- Uptake of carbon from the growth of trees through reforestation and afforestation
- Emission of carbon from logging, commercial forest product industries and informal fuelwood gathering

Forest conversion. This includes carbon emission from deforestation or conversion of forested area into other land uses through the following activities:

- Burning of aboveground biomass on site
- Burning of aboveground biomass utilized off site
- Remaining aboveground biomass left to decay

Abandonment of managed land. This refers to the uptake of carbon from the natural regeneration of forests in previously abandoned land and degraded forest areas where growth of trees is still expected.

Emission of non-CO_2 trace gases from forest clearing. These refer to releases of methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and oxide of nitrogen (NO_x) which result from the open burning of forest biomass after forest clearing.

6.2 METHODOLOGY

Estimates of GHGs from land use change and forestry in the present study are based on the following assumptions:

- The flux of CO_2 moving to or from the atmosphere is equal to changes in carbon stocks in existing biomass aboveground and belowground.
- The fate and amount of belowground biomass as well as soil carbon are ignored in the calculation.
- The net flux of carbon associated with forest fires is balanced, due to annual regrowth of ground vegetation.
- Degraded forest and secondary forest, which are derived from historically cleared natural forest or abandoned farmland, are considered to sequester carbon through the regrowth of trees and other vegetation.
- Biomass of all forest types is unchanged due to forest degradation over time.

The IPCC Unit for Greenhouse Gas Inventories has developed a software package to facilitate the calculation of greenhouse gas inventories. The software is based on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories and the commercial spreadsheet application Microsoft Excel. The present study utilizes this IPCC software package to calculate carbon emission and sequestration from land use change and forestry as shown in the Appendix (Table A6.1-A6.4).

6.3 DATA

Data used in the present study are gathered from different sources as well as from direct communications with experts. The values necessary in the present calculation can be categorized according to the IPCC Guidelines, as follows:

Changes in Forest and Other Woody Biomass Stocks

Vegetation withdraws CO_2 from the atmosphere through the process of photosynthesis and stores the carbon produced mostly in the woody biomass of trunks, branches and roots. The removal of woody biomass causes the release of the stored carbon into the atmosphere through the oxidation and decaying processes. This section focuses mostly on the changes in forest and biomass stocks arising from the use of woody biomass and from the growing of trees in plantation forest.

Area of Forest Plantation

Reforestation in Thailand first started with only a small area in 1906. However, the reforestation program has expanded more rapidly since the start of the 1st National Economic and Social Development Plan (NESDP) in 1961. There are four main groups involved in reforestation programs in Thailand, namely, the Royal Forest Department (RFD), Forest Industries Organization (FIO), Thai Plywood Company (TPC), and the private sector. The private sector started planting commercial forest about 15 years ago and at present account for a big share of commercial forest plantation in Thailand. The major tree species planted by the private sector is *Eucalyptus camaldulensis*.

Data on the area of plantation is generally scattered among the organizations that are responsible for the different planting programs. For the RFD alone, there are several divisions involved in reforestation programs, e.g., State Reforestation Division, Private Reforestation and Extension Division, Forest Research Office, King's Initiative Project, and Reforestation Campaign in Commemoration of the Royal Golden Jubilee Project. Luangjame (1997) has compiled data on reforestation area, by species, for the period 1961-1996. In order to get data on the plantation area until 1994, the planting areas in 1995-1996 were subtracted from data reported by Luangjame (1997). To simplify the estimation, the planted species of trees were broken down into six categories, including teak, *Eucalyptus*, pines, *Rhizophora*, fast growing species, and slow growing species (see Table 6.1).

In 1994, the government launched the Reforestation Campaign in Commemoration of the Royal Golden Jubilee to celebrate the 50th anniversary of His Majesty the King's accession to the throne by planting 0.8 million ha of trees throughout the country within 5 years. The project was aimed at rehabilitating conservation and non-conservation areas as well as areas along the roadsides. Some 45,871 ha and 11,410 km of roadsides trees were planted in the same year (Luangjame 1997). Assuming that the success rate of planting under this program was 625 trees per ha and 1,000 trees per km, a total of 40 million seedlings were successfully planted in 1994. This number of seedlings is approximately 15 percent of the total number of seedlings produced for this project in that year.

Table 6.1 Total Reforestation Area in Thailand

Plantation species	Area of plantation (Thousand ha)
Tectona grandis	254.6[1/]
Eucalyptus	225.6[2/]
Pinus	30.5[1/]
Rhizophora	4.5[1/]
Fast growing species	54.7[1/]
Slow growing species	111.3[1/]

Sources: [1/] Luangjame (1997) and State Forest Division, Royal Forest Department (personal communication)
[2/] Luangjame (1997) and Suntornhow (1999)

Annual Growth Rate of Plantation Species

The present calculation method utilized the annual growth rate of plantation species compiled by Boonpragob (1996). These figures, which were derived from local publications, were calculated by dividing the biomass at maturity by the rotation period (see Table 6.2). The IPCC default values were used when local values were unavailable. The annual growth rate of the first year seedlings planted under the Reforestation Campaign in Commemoration of the Royal Golden Jubilee Project was assumed to be approximately 0.7 tonnes dry matter (dm) per 1,000 seedlings (Thoranisorn, 1991).

Carbon Content of Dry Biomass

In order to convert dry biomass into carbon for emission estimation, the IPCC Guidelines recommended a conversion fraction of 0.5 for the calculation of all biomass. Since more accurate conversion values are not available, the default value provided by the IPCC was used in the present estimation.

Commercial Harvest of Woody Biomass

Although the logging ban in Thailand has been imposed since January 1989, production of timber from natural forest was still reported. However, the amount of timber produced was only one quarter of the production before the logging ban was implemented. Most of the wood for domestic consumption is now imported and only a small portion is harvested from commercial plantation and private land. The amount of round wood biomass harvested in 1994 was 62,327 cu m (RFD, 1997), most of which were assumed to be used in the domestic wood industry.

Fuel wood production, which is officially reported by the Royal Forest Department, is considered to be much lower than the actual domestic fuel wood consumed. Generally, rural households gather fuel wood from various sources, e.g., natural forest, degraded forest, and tree crops from private farms. The Thai Forestry Sector Master Plan (TFSMP, 1993) estimated that domestic fuel wood supply from various sources in 1994 amounted to 46.5 million cubic meters, while the Royal Forest Department reported that fuel wood production from forest was only 0.2 million cu m in the same year (RFD, 1994). This study utilized the amount of fuel wood reported by TFSMP (1993).

Table 6.2 Annual Growth Rate of Plantation Species in Thailand

Plantation species	Annual growth rate (t dm/ha)
Tectona grandis	15.1
Eucalyptus	17.4
Pinus	11.0
Rhizophora	14.8
Fast growing species	10.3
Slow growing species	6.8

Sources: Boonpragob (1996)

Statistics on the commercial harvest of timber, fuel wood and charcoal are generally provided by volume. Therefore, it is necessary to convert these values into dry matter. The IPCC recommends a general default value of 0.65 tonne dm per cu m for deciduous trees. This study utilizes this value.

Forest Conversion

Carbon flux from deforestation and land use change is considered a prominent factor in the study of climate change. However, the calculation method in this category is in many ways the most complex of the emissions inventory components. Forested land can be converted into a wide variety of other uses, including agriculture and urban development. The main underlying cause of forest conversion in Thailand, though, appears to be the increasing demand for land for agriculture purposes to meet the needs of the growing population. This section therefore presents the estimates of carbon released from biomass through the conversion of forest into agricultural land.

Once the forest is converted, biomass carbon in trees as well as carbon stored in the soil are disturbed and ultimately released into the atmosphere through a number of processes, including biomass burning, decomposition of plant residues, and decaying of used timber. The amount of carbon flux due to forest conversion differs from region to region, depending upon the land use change activity and the cultural practice of local people.

Estimated Forest Conversion in the Base Year 1994

Natural forests in Thailand are generally classified into five distinct types, as follows:

Tropical Evergreen Forest (EGF). This type of forest accounts for 43 percent of the total forest area, and has the greatest species diversity. It is composed of several subtypes and distributed widely throughout southern Thailand and the mountain areas in the north and west. The trees maintain their leaves throughout the year. The main species are from the family of Dipterocarpaceae.

Mixed Deciduous Forest (MDF). This type of forest is mostly found in low elevation areas in the north and west, and covers about 22 percent of the total forest area. Deciduous forests are characterized by leaf shedding during the dry season. The subtypes of this forest include mixed deciduous forest, with teak and without teak.

Dry Dipterocarp Forest (DDF). This is the main forest type in the north and northeast, and occupies a wide range of elevations. It covers about 30 percent of the total forest area. This type of forest has low species diversity and low production. Forest fires often occur during the dry season.

Pine Forest (PF). This is primarily found in small pockets in mountainous areas in the north and northeast. Only two pine species, namely, *Pinus merkusii* and *Pinus kesiya*, are native to Thailand.

Mangrove Forest (MGF). This type of forest is generally found along river estuaries and muddy coastlines. The major species are those in the *Rhizophoraceae* family. About 73 percent of the mangrove forests in Thailand are found along the east and west coast of the southern peninsula.

Since 1973, the Royal Forest Department has applied remote sensing technique using visual interpretation of LANDSAT imagery at the scale of 1:250,000 to assess the existing forest area of the country. However, the assessment of the forest areas was not conducted in every year in 1994, the base year for GHG inventories. There was no interpretation of forest area. The interpretations of the LANDSAT imageries were carried out for the years 1993 and 1995 (see Table 6.3). Since the IPCC Guidelines recommended that the estimate of forest loss in the base year be taken from the average losses of forest area in adjacent years (before and after the base year), the present

Table 6.3 Forest Area in Thailand, 1985-1995

Year	Forest area (Mil. ha)	percent of country area	Remarks
1985	15.09	29.40	LANDSAT - 3 and 4
1988	14.38	28.03	LANDSAT - 4 and 5
1989	14.34	27.95	LANDSAT - 4 and 5
1991	13.67	26.64	LANDSAT - 5 (TM)
1993	13.36	26.03	LANDSAT - 5 (TM)
1995	13.15	25.62	LANDSAT - 5 (TM)
Average forest area changed per year	0.174		

Source: Royal Forest Department (1997)

estimate of forest loss is therefore the average loss of 1993 and 1995.

The interpretation of the forest areas, by type and region, was done only once in 1982 (see Table 6.4). Hence, the loss of forest area, by type, in the inventory year was estimated using the ratio of each forest type as observed in 1982, even though the changes of forest area in each forest type are known to be different. Moreover, it is assumed that the rates of change in each forest type are the same: EGF shared about 43 percent of the total forest area, while MDF, DDF, PF and MGF occupied approximately 22 percent, 31 percent, 1 percent and 2 percent, respectively. Others types of forest, including scrub forest, contributed very small amounts of less than 1 percent (Table 6.5).

Aboveground Biomass Density and Carbon Content of the Dry Biomass

Biomass density varies markedly among forest types. Within the same forest type, biomass density is also found to differ from place to place. There is still a wide range of uncertainty in these values. The present method of calculation utilizes the values of aboveground biomass and carbon content of dry biomass which have been earlier gathered and reported by Boonpragob (1996). These are shown on Table 6.6. Biomass of various forest types is assumed to be unchanged due to forest degradation over time.

Aboveground Biomass After Forest Conversion

More than 70 percent of deforested areas in Thailand are converted into agricultural lands (Panayotou and Parasuk, 1990). The replacement crops vary from annual crops to perennial crops and trees such as tea, cocoa, coffee and para-rubber. The IPCC recommends a default value of 10 tonnes of dry biomass per ha of agricultural crops. This value is used in the present calculation for the replacement of MDF, DDF and PF. For EGF, where the major replacement crops are perennial plants, a value of 15 tonnes of dry biomass per ha is used. The only exception is MGF, where most of the converted mangrove forests are used for black tiger prawn farming and leave hardly any vegetation in the area.

Fraction of Cleared Biomass Fate

The fate of aboveground biomass after forest conversion include being burned on site, being burned off site, and being left to decay. After the forest is cleared, it is assumed that only stemwood biomass is removed from the area and that all the remaining aboveground biomass are left for burning on site. Of the stemmed biomass removed, 50 percent are assumed to come out as waste in their conversion into wood products (Visutthithepakul, 1999). These wastes are assumed to be a substitute for fuels and burned off site. The

Table 6.4 Forest Area, by Type, 1982

	Forest type						
	EGF	MDF	DDF	PF	MGF	Others	Total
Forest area (Thousand ha)	6,786.1	3,392.9	4,893.0	216.2	287.2	84.6	15,660.0
Proportion	0.43	0.22	0.31	0.01	0.02	0.01	1.0

Source: Royal Forest Department (1997)

Table 6.5 Estimated Forest Area, by Forest Type, in Thailand (1993-1995) and the average Annual Change

Forest type	Estimated forest area (Thousand ha)			Average change in forest areas per year (Thousand ha)
	1993	1994	1995	
EGF	5,787.43	5,742.57	5,697.77	44.83
MDF	2,893.58	2,871.16	2,848.76	22.41
DDF	4,172.92	4,140.58	4,108.28	32.32
PF	184.38	182.95	181.53	1.43
MGF	244.93	243.04	241.14	1.90
Others	72.15	71.59	71.03	0.56
Total	**13,355.40**1/	**13,251.90**2/	**13,148.50**1/	**103.45**

Note: 1/ Forest area acquired from the interpretation of LANDSAT imageries (RFD 1997)

2/ Derived from forest areas in 1993 and 1995 and deforestation rate between 1993 and 1995.

remaining stemwood biomass is assumed to be lost through the natural decaying process.

The IPCC recommends a 10-year period for the decaying process. This period is considered to be too short for construction timber to decay. However, since most timber cleared by forest conversion is for rural consumption, the 10-year period is considered acceptable. This default value is therefore used in the present estimation. The total carbon being released into the atmosphere in the inventory year is therefore a function of the land-clearing rate for each of the past 10 years. To simplify the calculations, IPCC allows the use of decade average values for the land clearing and for portions left to decay.

Fraction of Biomass Oxidized

Of the total biomass associated with forest clearing that is burned off site as fuel and burned on site to facilitate agriculture, the IPCC recommends a value of 0.9 as the fraction of biomass that is completely oxidized and immediately emitted into the atmosphere. The balance of 0.1 is assumed to be residual biomass that is not oxidized and remains as charcoal which will gradually decay.

Fraction of Non-CO_2 Trace Gases

The burning of forest biomass associated with forest clearing also releases non-CO_2 trace gases as by products of combustion. The major trace gases are methane, (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), and oxides of nitrogen (NO_x). Emissions of trace gases are estimated by multiplying the emission ratio of the trace gases by the total carbon released from on site burning of cleared biomass. Table 6.7 presents the emission ratios of trace gases given by the IPCC.

Abandonment of Managed Lands

When managed lands are abandoned, carbon may re-accumulate in vegetation as well as in the soil. Carbon uptake is therefore expected in this situation. However, only the carbon accumulated in aboveground biomass is considered. The return of forest biomass into their previous natural condition generally takes longer than 100 years (IPCC, 1996). In Thailand, it is estimated to take between 100-200 years for bare land to return to the level of biomass in an undisturbed state (Dhanmanonda, 1994). The IPCC (1996) recommends that abandoned lands be evaluated for two time horizons: a 20-year period and a period between 20-100 years.

Table 6.6 Values of Aboveground and Stem Wood Biomass and Carbon Content of Dry Biomass, by Various Forest Types

	EGF	MDF	DDF	PF	MGF
Carbon content of dominant species (percent)	54[1/]	52[1/]	49[2/]	48[3/]	55[4/]
Aboveground biomass (t/ha)	337[5/]	266[6/]	126[7/]	160[7/]	200[8/]
Stemwood biomass (t/ha)*	229[6/]	149[9/]	88[7/]	102[10/]	162[4/]

Notes: [1/] Xu, 1992
[2/] Roslan,1992 (personal communication)
[3/] Tsutsumi *et al.*, 1983
[4/] Aksornkoae, 1989
[5/] Average value described by Boonpragob, 1996
[6/] Ogawa *et al.*, 1965
[7/] Sahunalu and Jamroenprucksa, 1980
[8/] Aksornkoae *et al.*, 1987
[9/] Sangtongpraw and Sukwong, 1981
[10/] Sahunalu *et al.*, 1981
* Estimated values by using the proportion of stemwood biomass to aboveground biomass described in Boonpragob, 1996

Source: Boonpragob (1996)

Table 6.7 Non-CO_2 Trace Gas Emission Ratios for Open Burning

Trace Gases	Emission Ratios	Conversion Ratios
CH_4	0.012 (0.009-0.015)	16/12
CO	0.060 (0.040-0.080)	28/12
N_2O	0.007 (0.005-0.009)	44/28
NO_x	0.121 (0.094-0.148)	46/24

Source: IPCC (1996)

Areas Abandoned

It is difficult to estimate the area of abandoned land in Thailand. This is partly due to the lack of inventory data on land utilization in the past. In order to retrieve data on abandoned land with vegetation regrowth, the present study assumed that forest areas, excluding National Parks, Forest Parks, Wildlife Sanctuaries and Non- Hunting Areas are in generally poor condition and continue to experience growth in vegetation. These areas were assumed to be disturbed by human activities more than 20 years ago. The area of forest with natural regrowth was estimated to be 5.9 million ha in 1994 (RFD, 1997). Idle lands, which are defined as areas that cannot grow any crops, including paddy, were estimated to be 0.5 million ha and were assumed to be abandoned for less than 20 years.

Annual Growth Rate of Natural Regeneration

The time scale for natural regeneration is generally much longer than any human being could follow. It is therefore difficult to estimate biomass accumulation from regrowth of natural vegetation. Dhanmanonda (1994) studied the process and rate of revegetation of dry dipterocarp and hill evergreen forests in Thailand, and estimated the turnover time to be between 100-200 years. Biomass accumulation was found to be rather slow in the beginning. This is inconsistent with data provided by the IPCC, which assumes rapid forest growth rate in the first twenty years (7 tonne dm per ha) and a slower rate of growth of 0.5 tonne dm per ha between 20-100 years.

In the present study, the growth of forest is based on the forest growth curve built by Dhanmanonda (1994). From the scheme of forest growth cycle, it is assumed the forest regrows to 20 percent of undisturbed forest biomass during the first twenty years and reaches a biomass density of 80 percent of undisturbed forest biomass in 100 years. Table 6.8 presents the estimated biomass of various forest types in each time period. A linear trend in the regrowth of aboveground biomass is assumed in the estimation.

6.4 RESULTS

Total Carbon Emission

The total carbon emission from forest for the base year 1994 is estimated at 27,157 Gg of carbon (Gg-C) or 99,577 Gg of carbon dioxide (Gg-CO_2). Of these, 10,958 Gg-C or 40,181 Gg-CO_2 were due to wood utilization, particularly fuelwood consumption, which took almost the entire share in this category. The remaining 15,843 Gg-C or 58,089 Gg-CO_2 arose from forest conversion activities, which include the natural decaying process from past land use activities (see Table 6.9).

Total Carbon Sequestration

The total carbon sequestered as a result of the growing of forest tree plantations, the natural regrowth of degraded forests, and the regeneration of abandoned lands is 10,664 Gg-C or 39,102 Gg-CO_2 (see Table 6.9). Although the annual growth rate of naturally regrowing vegetation is lower than for forest tree plantations, the amount sequestered is still high due to the larger area covered by forests that are degraded or in poor condition. However, carbon sequestration from natural regrowth in degraded forests and forest tree plantations is expected to be in opposite direction in the future.

Total Net Emission

Since the total emission exceeds total sequestration, land use changes and forestry sector activities contribute net carbon emissions to the atmosphere (see Table 6.9). In 1994, the net carbon emission from forest totaled 16,493 Gg-C or 60,476 Gg-CO_2.

Table 6.10 presents a comparison of net carbon emission from Thai forests in 1990 and 1994. The results show that the net carbon dioxide contribution from the forestry sector decreased. This could be partly due to the expansion of forest plantations and a decrease in deforestation area. The Thai government has placed much effort to increase forest areas in the country. In spite of this, emissions from fuelwood consumption were found to almost double in 1994. In order to reduce or to keep emissions of carbon dioxide from the forestry sector steady, fuelwood consumption must be restrained.

Non-CO_2 Trace Gases

Non-CO_2 trace gases that are emitted from the open burning of aboveground biomass after forest conversion are considered small compared to emissions of carbon dioxide. In 1994, the emissions of methane, (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), and oxides of nitrogen (NO_x) were estimated at 59.57, 521.21, 0.41 and 14.80 Gg, respectively, as shown in Table 6.11.

Compared to those in 1990, emissions of all non-CO_2 trace gases increased in 1994 (see Table 6.11). Although the amounts of trace gases are relatively small compared to carbon dioxide, their increasing trend demands more serious consideration and additional research.

Table 6.8 Estimated Annual Rate of Aboveground Biomass Regrowth in Abandoned Land, by Forest Type

Period (years)	Annual growth rate of aboveground biomass (t dm/ha)				
	EGF	MDF	DDF	PF	MGF
<20	3.37	2.66	1.26	1.6	2
20-100	2.25	1.77	0.84	1.07	1.33

Table 6.9 Estimates of Carbon and Carbon Dioxide Emission and Sequestration from Forests, 1994 (Gg)

	C	CO_2
Net Emission	**+16,493.39**	**+60,475.75**
Carbon sequestration	***-10,664.07***	***-39,101.60***
Uptake from plantation[1/]	-4,761.07	-17,457.26
Uptake from secondary forest[3/]	-5,903.00	-21,644.34
Total emission	***+27,157.46***	***+99,577.35***
Change in woody biomass	**+10,958.32**	**+40,180.51**
Wood and fuelwood consumption[1/]	+10,958.32	+40,180.51
Forest conversion	**+16,199.14**	**+59,396.84**
Biomass burning on site[2/]	+3,722.94	+13,650.78
Biomass burning off site[2/]	+3,956.75	+14,508.08
Decay of timber biomass[2/]	+8,519.45	+31,237.98

Note : [1/] See Table A6.1
[2/] See Table A6.2
[3/] See Table A6.3

Table 6.10 Comparison of Carbon Dioxide Emission and Sequestration from Forests, 1990 and 1994 (Gg)

	1990	1994
Net Emission	**+77,920.22**	**+60,475.75**
Carbon sequestration	***-24,964.10***	***-39,101.60***
Uptake from plantation	-812.50	-17,457.26
Uptake from secondary forest	-24,151.60	-21,644.34
Total emission	***+102,884.32***	***+99,577.35***
Change in woody biomass	**+21,160.59**	**+40,180.51**
Wood and fuelwood consumption	+21,160.59	+40,180.51
Forest conversion	**+81,723.73**	**+59,396.84**
Biomass burning on site	+6,455.61	+13,650.78
Biomass burning off site	+68,321.84	+14,508.08
Decay of timber biomass	+6,946.28	+31,237.98

Table 6.11 Comparison of Non-CO_2 Trace Gases Emission from Forest Clearing, 1990 and 1994 (Gg)

Trace gases	1990	1994
CH_4	28.170	59.57
CO	246.486	521.21
N_2O	0.194	0.41
NO_x	7.000	14.80

In summary the present study estimates GHG emission and sequestration due to land use change and forestry activities, following the most recent IPCC Guidelines (IPCC, 1996). However, several uncertainties remain unresolved, including the rate of change in forest areas by each forest type, the use of land after forest conversion, biomass density, and the fate of biomass after deforestation as well as the amounts of soil carbon and underground biomass.

The net carbon emission from the forestry sector for the base year 1994 is 16,493 Gg-C or 60,476 Gg-CO_2. This amount is only 70 percent of the net emission from the forestry sector in 1990. Although there was a declining trend in net carbon emissions from the forestry sector due to the expansion of forest plantation areas and reduced deforestation, the Thai government should continue to intensify its reforestation program. At the same time, it should implement measures to protect and promote the sustainable use of natural forests. These will show Thailand's willingness to safeguard the national, regional and global environment.

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APPENDIX

Table A6.1 Calculation Worksheet on Changes in Forest and other Woody Biomass Submodule

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**
WORKSHEET	**5-1**
SHEET	**1 OF 3**
COUNTRY	**Thailand**
YEAR	**1994**

					STEP 1		
			A	B	C	D	E
			Area of Forest/ Biomass Stocks (kha)	Annual Growth Rate (t dm/ha)	Annual Biomass Increment (kt dm)	Carbon Fraction of Dry Matter	Total Carbon Uptake Increment (kt C)
					C = (A x B)		E = (C x D)
Tropical	Plantations	*Tectona grandis*	254.6	15.1	3,844.46	0.5	1,922.23
		Eucalyptus spp.	225.6	17.4	3,925.44	0.5	1,962.72
		Pinus sp.	30.5	11.0	335.50	0.5	167.75
		Rhizophora	4.5	14.8	66.00	0.5	33.30
		Fast Growing species	54.7	10.3	563.41	0.5	281.71
		Slow Growing species	111.3	6.8	756.84	0.5	378.42
			A	B			
Non-Forest Trees (specify type)			Number of Trees (1000s of trees)	Annual Growth Rate (kt dm/1000 trees)			
			40,000.00	0.000747	29.88	0.5	14.94
						Total	4,761.07

Table A6.1 (Cont.)

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**
WORKSHEET	**5-1**
SHEET	**2 OF 3**
COUNTRY	**Thailand**
YEAR	**1994**

	STEP 2							
	F	G	H	I	J	K	L	M
Harvest Categories (specify)	Commercial Harvest (if applicable) (1000 m^3 roundwood)	Biomass Conversion/ Expansion Ratio (if applicable) (t dm/m^3)	Total Biomass Removed in Commercial Harvest (kt dm)	Total Traditional Fuelwood Consumed (kt dm)	Total Other Wood Use (kt dm)	Total Biomass Consumption (kt dm)	Wood Removed From Forest Clearing (kt dm)	Total Biomass Consumption From Stocks (kt dm)
			H = (F x G)	FAO data		K = (H + I + J)	(From column M, Worksheet 5-2, sheet 3)	M = K - L
Roundwood	62.327	0.65	40.51			40.51		
Fuelwood	46,483.00	0.65	30,213.95			30,213.95		
Total	46,545.33		30,254.46			30,254.46	8,337.82	21,916.65

Table A6.1 (Cont.)

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**
WORKSHEET	**5-1**
SHEET	**3 OF 3**
COUNTRY	**Thailand**
YEAR	**1994**

STEP 3		STEP 4	
N	O	P	Q
Carbon Fraction	Annual Carbon Release (kt C)	Net Annual Carbon Uptake (+) or Release (-) (kt C)	Convert to CO_2 Annual Emission (-) or Removal (+) (Gg CO_2)
	O = (M x N)	P = (E - O)	Q = (P x [44/12])
0.5	10,958.32	-6,197.26	-22,723.28

Table A6.2 Calculation Worksheet on Forest Conversion Submodule

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**1 OF 5 BIOMASS CLEARED**
COUNTRY	**Thailand**
YEAR	**1994**

		STEP 1				
		A	B	C	D	E
Vegetation types		Area Converted Annually (kha)	Biomass Before Conversion (t dm/ha)	Biomass After Conversion (t dm/ha)	Net Change in Biomass Density (t dm/ha)	Annual Loss of Biomass (kt dm)
					D = (B - C)	E = (A x D)
Tropical	EGF	44.83	337	15	322.00	14,435.26
	MDF	22.41	266	10	256.00	5,736.96
	DDF	32.32	126	10	116.00	3,749.12
	PF	1.43	160	10	150.00	214.50
	MGF	1.9	200	0	200.00	380.00
	Subtotal	102.89			1,044.00	24,515.84

Table A6.2 (Cont.)

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**2 OF 5 CARBON RELEASED BY ON-SITE BURNING**
COUNTRY	**Thailand**
YEAR	**1994**

		STEP 2					
		F	G	H	I	J	K
Vegegation types		Fraction of Biomass Burned on Site	Quantity of Biomass Burned on Site (kt dm)	Fraction of Biomass Oxidised on Site	Quantity of Biomass Oxidised on Site (kt dm)	Carbon Fraction of Above- ground Biomass (burned on site)	Quantity of Carbon Released (from biomass burned) (kt C)
			G = (E x F)		I = (G x H)		K = (I x J)
Tropical	EGF	0.32	4,619.28	0.9	4,157.35	0.54	2,244.97
	MDF	0.34	1,950.57	0.9	1,755.51	0.52	912.87
	DDF	0.30	1,124.74	0.9	1,012.26	0.49	496.01
	PF	0.36	77.22	0.9	69.50	0.48	33.36
	MGF	0.19	72.20	0.9	64.98	0.55	35.74
						Subtotal	3,722.94

Table A6.2 (Cont.)

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**3 OF 5 CARBON RELEASED BY ON-SITE BURNING**
COUNTRY	**Thailand**
YEAR	**1994**

		STEP 3						STEP 4
		L	M	N	O	P	Q	R
Vegetation types		Fraction of Biomass Burned off Site	Quantity of Biomass Burned off Site (kt dm)	Fraction of Biomass Oxidised off Site	Quantity of Biomass Oxidised off Site (kt dm)	Carbon Fraction of Above-ground Biomass (burned off site)	Quantity of Carbon Released (from biomass burned off site) (kt C)	Total Carbon Released (from on and off site burning) (kt C)
			M = (E x L)		O = (M x N)		Q = (O x P)	R = (K + Q)
Tropical	EGF	0.34	4,907.99	0.9	4,417.19	0.54	2,385.28	4,603.25
	MDF	0.33	1,893.20	0.9	1,703.88	0.52	886.02	1,798.88
	DDF	0.35	1,312.19	0.9	1,180.97	0.49	578.68	1,074.69
	PF	0.32	68.64	0.9	61.78	0.48	29.65	63.01
	MGF	0.41	155.80	0.9	140.22	0.55	77.12	112.86
		Subtotal	8,337.82				3,956.75	7,679.69

Table A6.2 (Cont.)

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**4 OF 5 CARBON RELEASED BY DECAY OF BIOMASS**
COUNTRY	**Thailand**
YEAR	**1994**

					STEP 5					
		A	B	C	D	E	F	G	H	I
Vegetation types		Average Area Converted (10 Year Average) (kha)	Biomass Before Conversion (t dm/ha)	Biomass After Conversion (t dm/ha)	Net Change in Biomass Density (t dm/ha)	Average Annual Loss of Biomass (kt dm)	Fraction Left to Decay	Quantity of Biomass Left to Decay (kt dm)	Carbon Fraction in Above-ground Biomass	Carbon Released from Decay of Above-ground Biomass (kt C)
					D = (B-C)	E = (A x D)		G = (E x F)		I = (G x H)
Tropical	EGF	86.43	337	15	322.00	27,830.46	0.34	9,462.36	0.54	5,109.67
	MDF	44.22	266	10	256.00	11,320.32	0.33	3,735.71	0.52	1,942.57
	DDF	62.31	126	10	116.00	7,227.96	0.35	2,529.79	0.49	1,239.60
	PF	2.01	160	10	150.00	301.50	0.32	96.48	0.48	46.31
	MGF	4.02	200	0	200.00	804.00	0.41	329.64	0.55	181.30
									Subtotal	8,519.45

Table A6.2 (Cont.)

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**5 OF 5 CARBON RELEASED BY DECAY OF BIOMASS**
COUNTRY	**Thailand**
YEAR	**1994**

STEP 6			
A	B	C	D
Immediate Release From Burning (kt C)	Delayed Emissions From Decay (kt C) (10-year average)	Total Annual Carbon Release (kt C)	Total Annual CO_2 Release (Gg CO_2)
	O = (M x N)	P = (E - O)	Q = (P x [44/12])
7,679.69	8,519.45	16,199.14	59,396.84

Table A6.3 Calculation Worksheet of non-CO_2 trace gas from burning biomass on Forest Conversion Submodule

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**ON-SITE BURNING OF FORESTS - NON-CO_2 TRACE GASES FROM BURNING BIOMASS**
WORKSHEET	**5-3**
SHEET	**1 OF 1 NON-CO_2 GAS EMISSIONS**
COUNTRY	**Thailand**
YEAR	**1994**

STEP 1			**STEP 2**				
A	B	C		D	E	F	G
Quantity of Carbon Released (kt C)	Nitrogen- Carbon Ratio	Total Nitrogen Released (kt N)		Trace Gas Emissions Ratios	Trace Gas Emissions (kt C)	Conversion Ratio	Trace Gas Emissions from Burning of Cleared Forests (Gg CH_4, CO)
(From column K, sheet 2 of Worksheet 5-2)		C = (A x B)			E = (A x D)		G = (E x F)
			CH_4	0.012	44.68	16/12	59.57
			CO	0.06	223.38	28/12	521.21
					(kt N)		(Gg N_2O, NOx)
3,722.94	0.01	37.23			E = (C x D)		G = (E x F)
			N_2O	0.007	0.26	44/28	0.41
			NO_x	0.121	4.50	46/14	14.80

Table A6.4 Calculation Worksheet on Abandonment of Managed Lands Submodule

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**ABANDONMENT OF MANAGED LANDS**
WORKSHEET	**5-4**
SHEET	**1 OF 3 CARBON UPTAKE BY ABOVEGROUND REGROWTH - FIRST 20 YEARS**
COUNTRY	**Thailand**
YEAR	**1994**

		STEP 1				
		A	B	C	D	E
Vegetation types		20-Year Total Area Abandoned and Regrowing (kha)	Annual Rate of Aboveground Biomass Growth (t dm/ha)	Annual Aboveground Biomass Growth (kt dm)	Carbon Fraction of Aboveground Biomass	Annual Carbon Uptake in Aboveground Biomass (kt C)
				C = (A x B)		E = (C x D)
Tropical	EGF	222	3.37	748.14	0.54	404.00
	MDF	114	2.66	303.24	0.52	157.68
	DDF	161	1.26	202.86	0.49	99.40
	PF	5	1.6	8.00	0.48	3.84
	MGF	10	2	20.00	0.55	11.00
					Subtotal	675.92

Table A6.4 (Cont.)

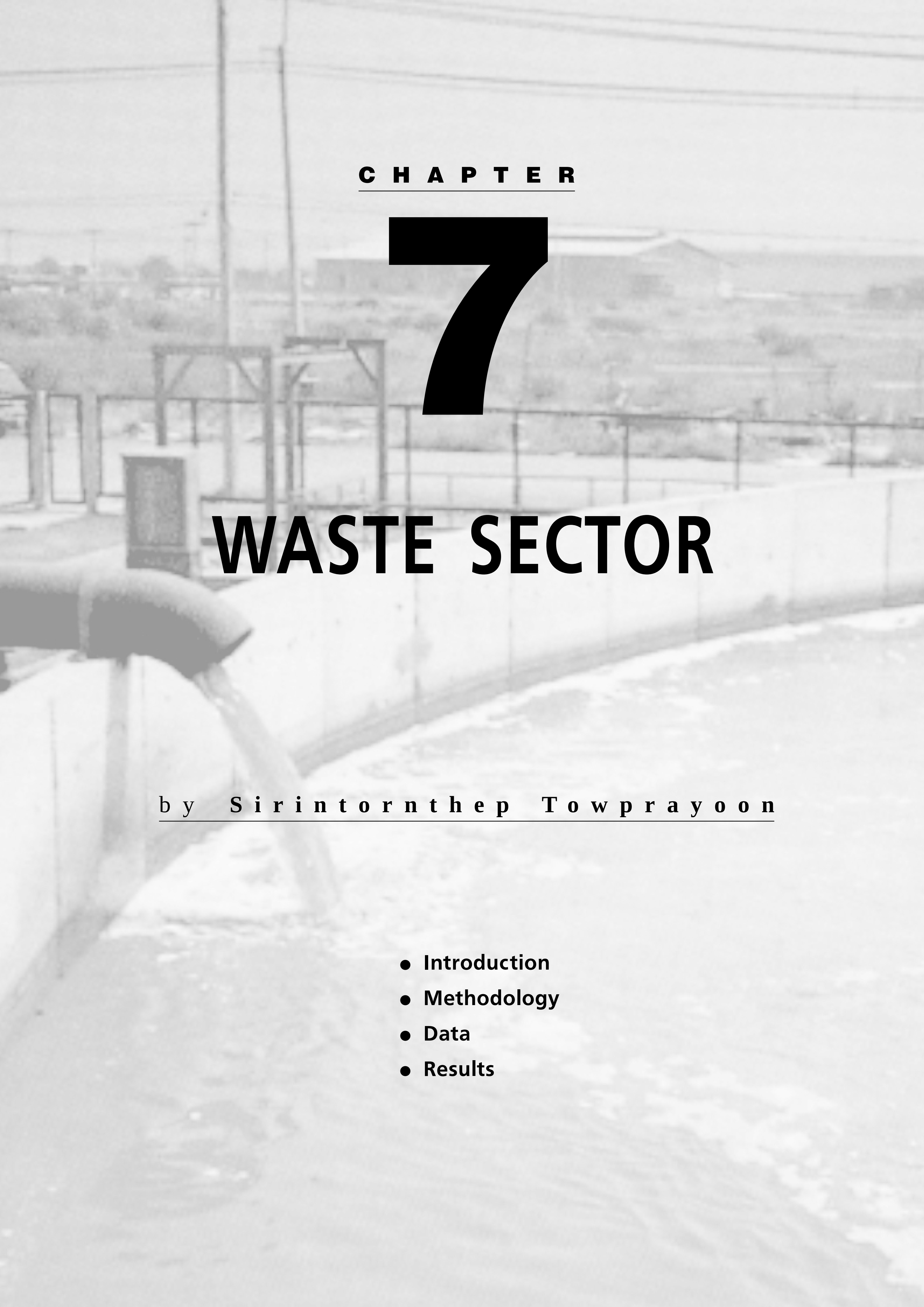
MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**ABANDONMENT OF MANAGED LANDS**
WORKSHEET	**5-4**
SHEET	**2 OF 3 CARBON UPTAKE BY ABOVEGROUND REGROWTH - > 20 YEARS**
COUNTRY	**Thailand**
YEAR	**1994**

				STEP 2		
		G	H	I	J	K
Vegetation types		Total Area Abandoned for more than Twenty Years (kha)	Annual Rate of Aboveground Biomass Growth (t dm/ha)	Annual Aboveground Biomass Growth (kt dm)	Carbon Fraction of Aboveground Biomass	Annual Carbon Uptake in Aboveground Biomass (kt C)
				I = (G x H)		K = (I x J)
Tropical	EGF	2,577	2.25	5,798.25	0.54	3,131.06
	MDF	1,318	1.77	2,332.86	0.52	1,213.09
	DDF	1,857	0.84	1,559.88	0.49	764.34
	PF	60	1.07	64.20	0.48	30.82
	MGF	120	1.33	159.60	0.55	87.78
					Subtotal	5,227.08

Table A6.4 (Cont.)

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**ABANDONMENT OF MANAGED LANDS**
WORKSHEET	**5-4**
SHEET	**3 OF 3 TOTAL CO_2 REMOVALS FROM ABANDONED LANDS**
COUNTRY	**Thailand**
YEAR	**1994**

STEP 3	
L	M
Total Carbon Uptake from Abandoned Lands (kt C)	Total Carbon Dioxide Uptake (Gg CO_2)
L = (E + K)	M = (L x (44/12))
5,903.00	21,644.34



CHAPTER

7

WASTE SECTOR

by Sirintornthep Towprayoon

- Introduction
- Methodology
- Data
- Results

7.1 INTRODUCTION

The emission of greenhouse gases from the waste sector, comprising mostly methane, is produced via the anaerobic digestion of organic matter. The amounts of methane emitted depend mainly on the anaerobic activities and physical characteristic of waste. Greenhouse gases from this sector come from two main sources: (1) land disposal of solid waste; and (2) wastewater handling.

This study also discussed the possible policies and measures for mitigation options. The results are shown in the Appendix.

7.2 METHODOLOGY

Land Disposal of Solid Waste

In 1997, a group of researchers led by the Thailand Environment Institute (1996) prepared a national inventory of greenhouse gases for the year 1990 according to the 1995 IPCC guidelines (IPCC,1995). Emissions from the waste sector were included in the report.

Total methane emissions from solid waste disposal on land was estimated at 76.509 thousand tonnes or Gigagrams (Gg) for the year 1990. Since it was the first time that emissions from the waste sector were estimated, the IPCC default methodology using the theoretical gas yield was used. This method was based on a mass balance approach and did not incorporate any time factors into the methodology.

The default **theoretical gas yield methodology** was revised by the IPCC (1996) to improve its accuracy. This was done by introducing methane correction factors or default values to consider four different types of solid waste disposal sites (SWDS), namely: (1) managed, (2) unmanaged-deep (>5m waste), (3) unmanaged-shallow (<5m waste), and (4) uncategorized site. However, the basis for this methodology was still the mass balance approach where the amount of wastes generated from municipalities is taken into account.

In Thailand, more than half of the population still lives in rural areas where adequate waste management systems are not being implemented. Even in some urban communities, municipality waste collection systems are unavailable. Therefore, the amount of wastes generated was estimated using the number of population, less the rural population. This is one of the major uncertainties in estimating the amount of solid wastes for land disposal derived from waste collection.

The calculation is based on the following equation:

Landfill

Methane emissions from landfill (Gg/yr)
= Total MSW (Gg/yr)
x Fraction MSW landfilled
x Fraction DOC in MSW
x Fraction actual DOC dissimulated
x 0.55 g-C as CH_4/gC as biogas
x Conversion ratio (16/12)
– recovered CH_4 (Gg/yr)

Open Dumping

Methane emissions from open dumping (Gg/yr)
= Total MSW (Gg/yr)
x Fraction MSW opendumped
x Fraction DOC in MSW
x Fraction actual DOC dissimulated
x 0.275 g-C as CH_4/gC as biogas
x Conversion ratio (16/12)
– recovered CH_4 (Gg/yr)

where:

Total Municipal Solid Waste (MSW)
= population x waste generation rate

DOC = degradable organic carbon

To account for the time factor in emissions, the theoretical **first order decay methodology (FOD method)** was developed by the IPCC. This method acknowledges the fact that emissions of methane occur over long periods of time rather than instantaneously. The IPCC has recommended its use for countries with available data.

Unfortunately, representative data on SWDS for 1990 could not be obtained due to lack of proper data collection and local management system. The Pollution Control Department only began to establish country data on MSW treatment sites in municipalities and sanitary districts in 1994 (Pollution Control Department, 1994). The names of the municipalities covered are shown on Table A7.1 in Appendix.

In order to estimate more accurately the inventory of methane gas emissions from land disposal in the various SWDS, where data for 1994 were available, the FOD model was used.

The equation used for calculation is as follows:

Equation 1.

$$\textbf{Total methane emission} = \Sigma Q_n$$

where:

Q = total amount of methane gas generated in current year (cu m/yr)

n = SWDS in the country

Equation 2.

$$Q = LoR(e^{+kc} - e^{-kt})$$

where:

Lo = methane generation potential of waste (cu m/tonne)

R = average annual waste acceptance rate during active life (tonne/year)

k = decay constant for the rate of methane generation (per year)

c = time since SWDS closure (years)

t = time since SWDS opened (years)

Wastewater Handling

Domestic Wastewater

Emissions of greenhouse gases from domestic wastewater in Thailand were first reported in a study submitted by the Thailand Environment Institute (1996) to the Office of Environmental Policy and Planning in 1996. Methane emissions amounting to 2.279 Gg in the year 1990 were estimated using the 1995 IPCC methodology which was based on the number of population and wastewater generation rate.

The latest estimates, using the revised methodology of IPCC 1996, present a more accurate picture and are easier to calculate. The estimates of methane from domestic wastewater handling were therefore calculated following the revised method of IPCC 1996.

The equations used are as follows:

Equation 1.

$$TOW_{dom} = P \times D_{dom} \times (1\text{-}DS_{dom})$$

where:

TOW_{dom} = total domestic organic wastewater (kg-BOD/yr)

P = population (thousand persons)

D_{dom} = domestic degradable component (kg-BOD/yr)

DS_{dom} = fraction of domestic degradable organic component removed as sludge

Equation 2.

$$TOS_{dom} = P \times D_{dom} \times DS_{dom}$$

where:

TOS_{dom} = total domestic organic sludge (kg-BOD/yr)

Equation 3.

$$EF_i = Bo_i \times \Sigma (WS_{ix} \times MCF_x)$$

where:

EF_I = emission factor ($kg\text{-}CH_4/kg\text{-}DC$) for wastewater type i

DC = Degradable carbon

Bo_i = maximum methane producing capacity ($kg\text{-}CH_4/kg\text{-}DC$) for wastewater type i

WS_{ix} = fraction of wastewater type i treated using wastewater handling system x

MCF_x = methane conversion factors of each wastewater system

Equation 4.

$$EF_j = Bo_j \times \Sigma (SS_{jy} \times MCF_y)$$

where:

EF_j = emission factor ($kg\text{-}CH_4/kg\text{-}DC$) for sludge type j

Bo_j = maximum methane producing capacity ($kg\text{-}CH_4/kg\text{-}DC$) for sludge type j

SS_{jy} = fraction of sludge type j treated using wastewater handling system y

MCF_y = methane conversion factors of each wastewater system

Equation 5.

$$WM = \Sigma (TOW_i \times EF_i - MR_i)$$

where:

WM = total methane emission from wastewater in $kg\text{-}CH_4$

TOW_i = total organic wastewater type i in kg-DC/ yr.

EF_i = emission factor for wastewater type i in $kg\text{-}CH_4/kg\text{-}DC$

MR_i = total amount of methane recovered

Equation 6.

$$SM = \Sigma (TOS_j \times EF_j - MR_j)$$

where:

SM = total methane emission from sludge in $kg\text{-}CH_4$

TOS_j = total organic sludge type j in kg-DC/yr.

EF_j = emission factor for sludge type j in kg-CH_4/kg-DC

MR_j = total amount of methane recovered

Industrial Wastewater

The national greenhouse gas inventory prepared by the Thailand Environment Institute (1996) indicated that total emissions of methane from industrial wastewater treatment was 22.517 Gg in 1990. This estimate was based on the number of the factories that use anaerobic wastewater treatment facilities. The most recent IPCC 1996 methodology, meanwhile, segregates emissions into wastewater handling system and sludge handling system, which is suitable for a country with default values.

However, as Thailand has compiled its own database on some specific factories, the calculation method slightly differs from the original IPCC 1996 methodology as follows:

1. The degradable organic component is indicated in terms of BOD.
2. The total organic sludge in the anaerobic system is handled by drying and composting. Hence, no further anaerobic digestion is performed and the emission from sludge handling is zero.

The equations derived from the IPCC 1996 methodology are as follows:

Equation 5.

$$TOW_{ind} = Wo \times D_{ind} \times (1-DS_{ind})$$

where:

TOW_{ind} = total industrial organic wastewater (kg-BOD/yr)

Wo = wastewater outflow (cu m/yr)

D_{ind} = industrial degradable organic component (kg-BOD/cu m)

DS_{ind} = fraction of industrial degradable organic component removed as sludge

Equation 6.

$$TOS_{ind} = Wo \times D_{ind} \times DS_{ind}$$

where:

TOS_{ind} = total industrial sludge (kg-COD/yr)

The equations used for the emission factors (EF) and the total methane estimate (WM) are the same as for domestic wastewater in equations 3 and 4, respectively.

7.3 DATA

Land Disposal of Solid Waste

In 1994, according to records from the Pollution Control Department, there were 137 SWDS in Thailand, excluding those in Bangkok. These SWDS were categorized into five typical disposal types, namely: (1) trench dump, (2) open dump, (3) landfill, (4) burning, and (5) others. The number of disposal sites and the amounts of waste by disposal type are shown on Table 7.1.

Methane emissions were then calculated for three types of disposal sites, viz., trench dump, open dump and landfill. Burning, while considered a major disposal treatment, eliminated methane emissions. These three types of disposal sites covered about 47 percent of the total SWDS and accounted for 53 percent of the total wastes disposed. For solid waste disposal in Bangkok, emission estimates were made for two open dump sites, Nongkham and On-nuch, and a landfill site at Kampangsan.

Methane generation potential (*Lo*). The methane generation potential depends on several factors such as the composition of waste, type of land disposal, and age of the site. The USEPA recommends a value for *Lo* of 169.9 cu m CH_4 per tonne, while the IPCC suggests

Table 7.1 Number of Solid Waste Disposal Sites (SWDS) and Amount of Wastes by Disposal Types, 1994

Type of Disposal	Number of SWDS	Distribution of SWDS (percent)	Amount of waste (tonne/day)	Distribution of waste (percent)
Trench dump	34	24.8	1147.2	25.4
Opendump	8	5.8	215.7	4.8
Landfill	22	16.1	1039.0	22.9
Burning	70	51.1	1819.9	40.2
Others	3	2.2	301.0	6.7
Total	**137**	**100.0**	**4522.8**	**100.0**

Source: Pollution Control Department

180-200 cu m CH_4 per tonne in wet climate areas, 160-189 cu m CH_4 per tonne in medium moisture climate and 140-160 cu m CH_4 per tonne in dry climate. It has to be noted that these values represent the average methane generation potential of the total amount of waste over its lifetime in the land disposal site.

The values used in this estimate are based on studies of waste composition in the Bangkok metropolitan area and municipalities throughout Thailand as well as from research work undertaken elsewhere (details are shown in Appendix). Hence, the values for *Lo* used in this estimate are 121.4 cu m CH_4 per tonne for metropolitan landfill and 103.7 cu m CH_4 per tonne for municipalities landfill (Towprayoon and Masniyon, 1999). These values reduce by half the calculated emissions from trench dump and open dump sites.

Average annual waste acceptance rate (*R*). This is the average annual waste acceptance rate during the active lifetime of the SWDS. The data used for all the sites are shown on Table A7.1 in Appendix.

Methane generation rate constant (*k*). The value depends on the environment in which the SWDS is located. The IPCC recommends a range of between 0.003-0.4 per year. However, based on studies of site compaction and *k* values in the landfill sites around Thailand (see details in Appendix and Pollution Control Department, 1994), this study used two values of *k* according to compaction: 0.03 for trench dumping and open dumping sites and 0.04 for landfill sites.

Open and closure time (*c*,*t*). The values depend on the age of each site, which are available from the Pollution Control Department.

Wastewater Handling

Domestic Wastewater

Population. Data on population, divided into metropolitan areas and municipalities, are from the National Statistics Office (1990). The wastewater handling systems of these two areas are different. The population outside the municipalities is not taken into account, since there are no wastewater handling systems available in these areas.

Domestic degradable component (*DOC*). Recommended as BOD in wastewater handling in terms of kg-DC per 1,000 persons per year. The data is based on the ratio of the wastewater generation rate (160 liters per capita per day for metropolitan areas and 96 liters per capita per day for municipalities) (Surin, 1994) to the BOD rate of 150 mg per liter (Mongkol, 1988). As discharged wastewater has a regulated BOD limit of 20 mg per liter, the DOC in this estimate is based on the BOD consumed by the microbe in the wastewater system, which is 130 mg per liter.

Fraction of domestic degradable organic component removed as sludge. The fraction used in the estimate is 0.52. This figure is from the assumption that, in aerobic digestion systems, 52 percent of the BOD in domestic wastewater is consumed for microbial generation and accumulated as sludge in the system.

Maximum methane producing capacity. This is the maximum amount of methane that can be produced from a given quantity of wastewater. This estimate uses the default value for *Bo* of 0.25 as recommended by Lexmond, *et al.* 1995.

Methane conversion factors. The amount of methane that is actually emitted depends on the methane conversion factor. The MCF defines the portion of methane producing capacity that is achieved. The recommended MCF from anaerobic digestion is 0.7 and aerobic digestion is 0.

Fraction of wastewater treated using wastewater-handling system. The fractions used for anaerobic digestion, activated sludge and lagoons are 0.1, 0.4 and 0.5, respectively.

Industrial Wastewater

Type of industry. According to the Department of Industrial Works (DIW) database, there are 15 types of industries using anaerobic wastewater treatment. These can be grouped as follows: canneries, frozen food, fermented food, meat packing, dairy products, sugar, starch factory, fats and oil, coffee, soft drink, other food industry, paper and pulp, petrochemical, distillation, and others. These categories, based on the IPCC 1996 guidelines, are shown in Appendix.

Wastewater outflow. Data on wastewater outflow is from the DIW database as shown in Appendix.

Industrial degradable organic component. Industrial degradable organic component in terms of BOD per liter of wastewater is averaged from the existing data in the DIW database and Chavadej (1994). To obtain an average BOD rate, factories that use both aerobic and anaerobic wastewater treatment facilities were considered in order to achieve the most accurate value.

Fraction of industrial degradable organic component removed as sludge. The fraction used in this estimate is 0.2, since in the anaerobic digestion less organic compound is accumulated in the biomass compared to the aerobic system.

Fraction of wastewater treated using wastewater-handling system. The wastewater handling system for industrial anaerobic wastewater treatment is classified into 3 types, namely, anaerobic digestion, anaerobic filter and anaerobic pond. The fraction is calculated from the database of DIW.

7.4 RESULTS

Land Disposal of Solid Waste

Based on the foregoing data and assumptions, the total methane emissions from land disposal in 1994 were estimated at 19.567 Gg, of which 12.841 Gg (about 66 percent) were from Bangkok and 6.726 (about 34 percent) were from other municipalities. Table 7.2 summarizes the estimates of methane emissions from land disposal in Thailand for 1994.

A comparison of methane emission estimates from land disposal using the theoretical gas yield methodology and the IPCC FOD method as well as the recommended default values and locally estimated values were made. The results are illustrated in Figure 7.1.

The results show that when locally estimated values are used, the amount of methane emissions calculated is lower. Moreover, the use of the IPCC FOD method produces even smaller amounts of methane emissions. The local values used in the default IPCC model are waste generation rate, landfill fraction, and degradable organic carbon, while the local default values used in the FOD kinetics model are *Lo* and *k*.

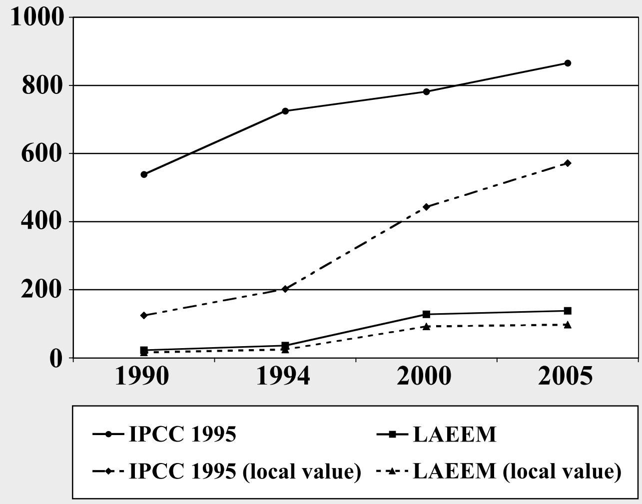
It should be noted that the estimates using the IPCC FOD model depend on the number of proper landfill sites. While the high emission estimates using the theoretical gas yield method may be due to a failure to incorporate the time element in emissions, the smaller emission estimates from the IPCC FOD model may also be due to incomplete data on landfill and open dump sites operated. It is clear from this exercise, though, that when local values are used, lower methane emissions from landfill site are estimated using both methods.

The results are also consistent with a recent report (see Jansens, 1999) presented at an expert group meeting which shows that the default IPCC model produces higher emission estimates than the FOD model using the same data base. It was therefore recommended that countries

Table 7.2 Estimates of Methane Emissions from Land Disposal, 1994

Disposal type	Methane Emissions (Gg)	Percent
Trench dump	1.851	
Opendump	0.371	
Landfill	4.505	
Subtotal - Municipalities	6.726	34.38
Opendump (Bangkok Nongkham)	4.458	
Opendump (Bangkok On-nuch)	4.425	
Landfill (Bangkok Kampangsan)	3.958	
Subtotal - Bangkok	12.841	65.62
Total	**19.567**	**100.00**

Figure 7.1 Comparison of Methane Emissions from Land Disposal Using Two Different Methods (Gg)



with enough historical data should calculate methane emissions using the FOD method, which is in closer agreement with the pattern of emissions arising from the degradation process.

A more accurate estimate of methane emissions is not only useful for preparing a national greenhouse gas inventory but also helps to plan mitigation options such as converting wastes into energy. The use of country values also helps to reduce uncertainties as well as to improve the quality of estimation.

Emissions from Domestic Wastewater

Using the IPCC 1996 methodology, methane emissions were estimated to come mostly from sludge handling. In 1994, total methane emissions were estimated at 1.77 Gg, of which 0.92 Gg were from sludge handling and 0.85 from wastewater handling. Using the same methodology to estimate emissions in 1990, the results show that only 1.58 Gg of methane were emitted, of which 0.82 Gg were from sludge handling and 0.76 Gg were from wastewater handling. This is about 30 percent lower than the earlier estimate of 2.279 Gg. The results for the year 1990 and 1994 are summarized on Table 7.3 below.

Emissions from Industrial Wastewater

Methane emissions in the IPCC 1996 methodology are determined mainly by the type of wastewater handling system used and by the fraction of DOC removed by sludge. The new estimates therefore show lower emissions than the previous ones because the most common system of sludge handling used is drying and the residue involved in the process, such as compost animal feed, does not produce greenhouse gases. Total methane emissions from industrial wastewater in 1990 and 1994 are estimated at 14.05 Gg and 13.88 Gg, respectively.

Table 7.3 Estimates of Methane Emissions from Domestic Wastewater Handling, 1990 and 1994 (Gg)

Sources	1990	1994
Wastewater handling	0.76	0.85
Sludge handling	0.82	0.92
Total	**1.58**	**1.77**

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APPENDIX

Policies and Measures for Waste Sector

Policies and Measures

Land Disposal

One of the options for reducing methane emissions from land disposal is to turn methane gas into energy through electricity generation. And since 1995, the Thai government has promoted electricity generation by the private sector through the Small Power Plant (SPP) and Intermediate Power Plant (IPP) production schemes.

Electricity generation from landfills is one of the potential SPP projects in the country. However, to be economic, the site should be large enough and a solid waste management plan has to be implemented systematically. One should choose an appropriate site for landfill operations that can effectively recover energy from the changeable waste composition to benefit from electricity generation. Presently, the existing landfill sites scattered throughout the country are relatively small and cannot recover energy effectively. Thus the appropriate landfill site in the future should be large enough to generate electricity on a commercial basis.

To accumulate large amounts of wastes, the landfill site should have a broad service area. The recommended strategy is to design a large and effective landfill site in each region or service area in order to collect wastes from the main provinces and their vicinity. The operations of the landfill site, including waste collection, could be run privately. The site would benefit more when located close to an industrial estate where they could sell electricity directly.

Using the USEPA's EPLUS model (USEPA, ADB and UN-ESCAP, 1996), the potentials for electricity generation from wastes in selected sites (Figure A7.1) throughout the country were estimated. The estimates assumed the development of landfill sites over a period of 15 years (1998-2013) and the construction of waste-to-energy projects over a 10-year period in each site. The amounts of electricity produced in seven recommended site locations and their corresponding service areas are shown on Table A7.1. Total electricity generation capacity throughout the country is about 75 megawatts (MW), excluding the electric generation potential from Bangkok's municipal solid wastes.

Wastewater Handling

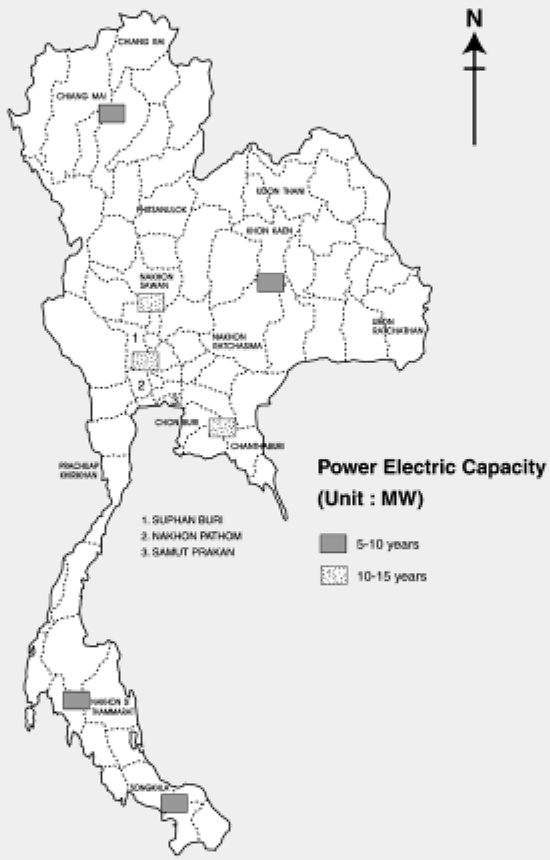
Domestic Wastewater

In making forecasts of methane emissions from domestic wastewater handling, it is important to note that several central wastewater treatment plants are planned for establishment in various cities throughout the country. However, all of them focus on aerobic treatment. The amount of domestic wastewater also depends highly on population growth. Thus, the assumed growth rate in population of 1.4 percent annually has important implications on the amount of emissions. The forecasts of methane emissions from 1990-2010 are shown on Table A7.2 below.

In order to reduce methane emissions from domestic wastewater handling, two major policies should be taken into account:

1. **Management Policy**. The present management system for domestic wastewater in each municipality is not done in a proper manner. Moreover, there are no treatment plants in many municipalities, while some municipalities use public lagoons as stabilization and aerobic ponds. In Bangkok, four treatment plants are currently being constructed to accept all wastewater discharges from the metropolitan area. Every municipality should plan to set up a standard wastewater treatment plant in their local area. Large housing estates or clusters of residential areas where discharged wastewater can be possibly pooled together should establish their own treatment plant and treatment system. Only standard effluents can be discharged to the local reservoir.
2. **Technology Policy**. There are two promising systems to treat domestic wastewater-aerobic system where large amounts of sludge are produced and anaerobic system where methane is emitted. The choice of which system to develop depends on a number of factors, including wastewater characteristics and properties, water volume, organic loading, budget, etc. If the aerobic system is chosen, one should take into consideration the amount of sludge produced and the immobilized microbes such as Rotating Biological Contractor (RBC). On the other hand, if the anaerobic system is selected, one should properly treat the sludge in order to reduce GHG emissions. Sludge composting or co-disposal with MSW in the methane recovery site are recommended. When the anaerobic system is used to treat domestic wastewater, it should be equipped with energy recovery devices for heat or electricity generation. The limitation is that the plant should be large enough to be attractive for enterprise or private operation.

Figure A7.1 Proposed Landfill Sites for Electricity Generation, by Region



Industrial Wastewater

Preparing forecasts of methane emissions from industrial wastewater is very difficult and uncertain, since anaerobic treatment depends on several factors such as the types of the industries present, wastewater characteristics, processes, appropriate technology, factory location, and amount of investment. There are no data available to indicate the demand for anaerobic systems in the future, although several innovative and promising technologies have been successfully researched and introduced into the country. Therefore, this study does not include forecasts of methane emissions from domestic wastewater treatment.

Technologies for industrial wastewater treatment, especially anaerobic treatment, are currently being applied to no more than 10 percent of the country's factories. The alternative uses of these technologies depend upon factory choice and other limitations.

Two policies to reduce GHGs from industrial wastewater can be set up. Firstly, the policy of waste minimization could be incorporated into the environmental management system (EMS) of industrial certification schemes such as ISO 14001. The aim is to cover as broadly as possible environmental management in the factory by encouraging less water usage, which lead to less wastewater discharge. Moreover, this strategy would also encourage efficient use of energy, which could become part of the mitigation options in the industrial sector.

Secondly, the policy of converting waste into energy could be applied to factories with anaerobic treatment technology. The methane produced from these factories could be utilized in boiler systems as pipeline gas or to generate electricity for use within the factory. Incentives for selling excess electricity to the main power grid should also be considered.

Table A7.1 Electricity Generation Potentials from Waste, by Region and Province (MW)

Region	Province	Generation Capacity (MW)	Total Electricity (MW)
1. Northern region	Chiangmai*	3.191	6.32
	Chiangrai	1.042	
	Lamphun	0.938	
	Lampang	1.146	
2. Central region 1	Lopburi*	2.637	12.22
	Nakornsawan	2.934	
	Saraburi	4.257	
	Angthong	1.579	
	Singburi	0.810	
3. Central region 2	Nonthaburi*	4.922	13.61
	Nakornpathom	1.932	
	Patumthani	2.188	
	Ayuthaya	2.830	
	Suphanburi	1.740	
4. Northeast region	Nakorn Rachasima*	4.257	10.21
	Khon Kaen	3.535	
	Buriram	1.699	
	Chaiyaphum	0.721	
5. Eastern region	Chonburi*	6.710	13.62
	Chanthaburi	2.461	
	Rayong	2.998	
	Chacheongsao	1.451	
6. Southern region 1	Nakorn Sri Thammarat*	3.014	9.68
	Suratthani	2.942	
	Krabi	0.794	
	Trang	2.180	
	Pattalung	0.746	
7. Southern region 2	Songkla*	5.002	9.23
	Pattani	1.643	
	Yala	1.796	
	Satun	0.786	
Total			**75.00**

* recommended site location

Table A7.2 Estimates of Methane Emissions from Domestic Wastewater, 1990-2010

Year	Emissions from wastewater (Gg)	Emissions from sludge (Gg)	Total (Gg)
1990	0.76	0.82	1.58
1994	0.85	0.92	1.77
1997	0.88	0.96	1.85
2000	0.92	1.00	1.92
2005	1.00	1.08	2.08
2010	1.06	1.15	2.21

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