ESTIMATION OF THE GREENHOUSE GASES EMISSIONS IN THAILAND

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การประมาณค่าก๊าซเรือนกระจกในประเทศไทย

นาย ศิวัตม์ ศรีเพ็ชร์พันธุ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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ESTIMATION OF THE GREENHOUSE GASES ÉMISSIONS IN THAILAND

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ศิวัตม์ ศรีเพ็ชร์พันธุ์ : การประมาณค่าก๊าซเรือนกระจกในประเทศไทย (ESTIMATION OF THE GREENHOUSE GASES EMISSIONS IN THAILAND) อาจารย์ที่ปรึกษา : ดร. สุดจิต ครุจิต, 161 หน้า. ISBN 974-533-079-5

การศึกษานี้ทำการประมาณค่าก๊าซเรือนกระจกในประเทศไทยปี พ.ศ 2533 2538 และ 2541 จากแหล่งต่างๆ ได้แก่ในส่วนของ ภาคพลังงาน ภาคกระบวนการผลิตทางอุตสาหกรรม ภาคการเกษตร ภาคป่าไม้ และภาคของเสีย และเปรียบเทียบความแตกต่างระหว่างแหล่งต่างๆ รวมถึงในกลุ่มประเทศอื่นด้วย การประมาณค่านี้อ้างอิงวิธีการคำนวณของ Intergovernmental Panel for Climate Change (IPCC) เป็นหลัก ประกอบกับข้อมูลที่เกี่ยวข้องเพื่อใช้ในการคำนวณ นอกจากนี้ยังได้ทำการปรับปรุงวิธีของ IPCC เพื่อให้มีความเหมาะสมในการประมาณค่าก๊าซเรือนกระจกสำหรับประเทศไทยด้วย ผลของการศึกษา พบว่าภาคหลักที่ปลดปล่อยก๊าซเรือนกระจกในประเทศไทย ได้แก่ ภาคพลังงาน ภาคการเกษตร และภาคป่าไม้ ในปี พ.ศ 2541 ทั้ง 3 ภาคนี้มีการปลดปล่อยก๊าซเรือนกระจกในหน่วยเทียบเท่าคาร์บอนไดออกไซด์ (CO_2) ออกมาถึงร้อยละ 92 สำหรับภาคพลังงานและภาคป่าไม้มีการปลดปล่อยก๊าซ CO_2 มากกว่าร้อยละ 95 ของก๊าซเรือนกระจกทั้งหมดในหน่วยเทียบเท่า CO_2 ส่วนการปลดปล่อยก๊าซมีเทน CH_4 และก๊าซไนตรัสออกไซด์ (N_2O) ส่วนใหญ่มาจากภาคการเกษตรซึ่งมีการปลดปล่อยก๊าซ CH_4 มากกว่าร้อยละ 86 ของก๊าซเรือนกระจกทั้งหมดในหน่วยเทียบเท่า CO_2 ส่วนการเปรียบเทียบปริมาณก๊าซเรือนกระจกในกลุ่มประเทศต่าง ๆ พบว่า กลุ่มประเทศที่พัฒนาแล้วมีการปลดปล่อยปริมาณก๊าซ CO_2 มากกว่าร้อยละ 72 ของก๊าซเรือนกระจกทั้งหมดในหน่วยเทียบเท่า CO_2 ส่วนกลุ่มประเทศกำลังพัฒนามีค่าดังกล่าวเพียงร้อยละ 50 เท่านั้น และจากการพิจารณาด้านการปล่อยมลพิษควบคู่กับจำนวนประชากรและอัตราการเจริญเติบโตทางเศรษฐกิจ (GDP) สรุปได้ว่าการใช้เทคโนโลยีในการผลิตของกลุ่มประเทศพัฒนาแล้วมีประสิทธิภาพสูงกว่ากลุ่มประเทศกำลังพัฒนา

ผลของการศึกษานี้สามารถนำมาใช้เป็นประโยชน์สำหรับประเทศไทยในการวางกฎเกณฑ์และการวางแผนการลดการปลดปล่อยปริมาณก๊าซเรือนกระจกอย่างมีประสิทธิภาพต่อไป

สาขาวิชาวิศวกรรมสิ่งแวดล้อม	ลายมือชื่อนักศึกษา ....
ปีการศึกษา 2545	ลายมือชื่ออาจารย์ที่ปรึกษา ....

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GREENHOUSE GASES/EMISSION/ESTIMATION/IPCC

This study estimated the greenhouse gases (GHGs) emissions in Thailand for the years 1990, 1995, and 1998 from various sources including Energy, Industrial Processes, Agriculture, Forest, and Waste sectors; and compare results among different sectors and with other selected countries. The estimation method was based on the Intergovernmental Panel for Climate Change (IPCC) methodology (1996) and other relevant information. This study also addressed the importance of improvement and refinement of the current IPCC methodology for appropriate usage in Thailand. Results show that the major sectors responsible for emission of the GHGs in Thailand were Energy, Agriculture, and Forest sectors. The three sectors contributed 92% of the carbon dioxide (CO_2) equivalent GHGs emitted in 1998. CO_2 constitutes more than 95% of the total CO_2 equivalent GHGs emitted in Energy and Forest sectors. Agriculture sector is identified as a major emitting source of Methane (CH_4) and nitrous oxide (N_2O). CH_4 emission sector is more than 86% of the total CO_2 equivalent GHGs emission from Agriculture sector. From emission comparison among selected countries, CO_2 constitutes more than 72% of the total CO_2 equivalent GHGs emitted from developed countries and 50% from developing countries. Based on the consideration regarding the emissions, population, and gross domestic product (GDP), the results imply that the technology being used to generate products in developed countries is of higher efficiency than that of developing countries.

The results obtained from this study are useful to relevant parties in Thailand for formulating proper and effective action plans minimize the emission of these gases.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม	ลายมือชื่อนักศึกษา ....
ปีการศึกษา 2545	ลายมือชื่ออาจารย์ที่ปรึกษา ....

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CHAPTER I

INTRODUCTION

1.1 Introduction

The threat posed by the greenhouse effect and its potential to raise global temperature has become an important international environmental issue. Greenhouse gases (GHGs) including carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), and nitrous oxide (N_2O) are produced through a wide variety of human activities, ranging from industrial development to forest management and agricultural practices. Carbon dioxide, the most important greenhouse gas, is responsible for about half of the warming potential attributable to human activities (Intergovernmental Panel on Climate Change [IPCC], 1996b).

CO_2 is emitted through the combustion of fossil fuels as well as deforestation, whereas the growth of trees and forests absorbs this gas and transforms it into plant biomass. The latter process can be referred to as carbon sequestration, and is one of the most effective ways to reduce CO_2 in the atmosphere. CH_4 is usually generated from the decomposition of organic matter under oxygen deficient conditions. Waterlogged paddy fields, with less oxygenated soil, enhance the production of CH_4. In addition, enteric fermentation of ruminant animals favors CH_4 production through the digestion of feed aided by microbial activities. Wastewater treatment and sanitary landfill are also precursors of CH_4. Other than by natural processes, N_2O is emitted into the atmosphere through the use of nitrogen fertilizers, organic fertilizer, industrial production process, biomass burning etc.

The Kingdom of Thailand has achieved a high economic growth since 1985 where a significant change in its economic structure (from agricultural oriented to industrial oriented economy) has taken place. During the period of 1985 to 1995, the average annual economic growth rate was 9.02% (National Economic and Social Development Board [NESDB], 2000). It must be emphasized that this growth has

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In 1990, the world total emissions of GHGs; such as CO_2, CH_4 and N_2O were 26,000 million tonnes, 6,300 million tonnes of CO_2 equivalent and 1,860 million tonnes of CO_2 equivalent, respectively (IPCC, 1994, quoted in British Columbia Ministry of Environment, Land & Parks, http://www.elp.gov.bc.ca/epd/ar/climate/gccasu.html, 2000). In Thailand, the total emissions of these three gases in that year were 164 million tonnes, 58 million tonnes of CO_2 equivalent and 3 million tonnes of CO_2 equivalent, respectively (Thailand Environment Institute [TEI], 1997). This is just less than 1% of the world total emission of the CO_2 equivalent. The three sectors which emitted the largest quantities of GHGs in Thailand in 1990 were energy (79 million tonnes of CO_2 equivalent), forest (78 million tonnes of CO_2 equivalent) and agriculture (54 million tonnes of CO_2 equivalent), respectively (TEI, 1997). The per capita emission of GHGs (t-CO_2 equivalent per person) in Thailand in 1990 was about 4.03 less than that of the whole world (6.42). However in the year 1990, the GHGs emission intensity (t-CO_2 equivalent per US$ 1000 current GDP) of Thailand was about 2.6, whereas that of the whole world was only about 1.6. It is therefore necessary to try to gain a clear understanding about the current status and trend of the emission of greenhouse gases in Thailand. At the same time, improvement in the estimation methodology of such gases is the another important task.

1.2 Objectives of the study

The major objectives of this study were:

1.2.1 to estimate net greenhouse gases (GHGs) emission from all major sources including energy, industrial processes, agriculture, forest, and waste sectors of Thailand for the years 1990, 1995 and 1998.

1.2.2 to compare emissions of the greenhouse gases in Thailand among the years 1990, 1995, and 1998; among different sectors; and among different selected countries.

1.2.3 to improve and refine certain parts of the IPCC methodology to make it more suitable for application in Thailand.

1.3 Scopes of the Study

1.3.1 Greenhouse gas emission from energy sector was estimated from energy combustion and production activities, and from chemical reactions (flue gas desulfurization) in energy transformation processes based on the latest IPCC methodologies.

1.3.2 Estimation was done for greenhouse gases emission from industrial processes, namely cement, lime, glass, pulp and paper, iron and steel, petrochemical, and food and beverage industries, as classified by the Thailand Standard Industrial Classification (TSIC).

1.3.3 Emission of methane and other gases (such as N_2O) from enteric fermentation, rice cultivation, burning of some crop residues and agriculture soils was done based on the latest IPCC methodology.

1.3.4 Estimation of emission and sequestration of CO_2 primarily from activities related to utilization and replanting of trees and forest was done considering natural forests as carbon neutral. Thus, the natural forests are neither sources nor sinks of carbon. The study involves:

- changes in forest and other woody biomass stocks that include emission and sequestration of C by the following activities: (i) Uptake of C by biomass from the growth of trees through reforestration and afforesstation, and (ii) emission of C from biomass from harvesting timber in plantation of forest and fuel wood consumption.
- forest conversion/forest clearing that includes carbon emission from deforestation or forest clearing through the following activities: (i) Burning of above ground biomass on site (ii)

Decaying of timber biomass utilized off site (iii) Decomposition of above ground biomass on site.

- estimation of emission of non-CO_2 trace gases, such as CH_4 and N_2O from on-site burning of plant residues after deforestation.
- abandonment of managed land includes sequestration of C into plant biomass resulting from the natural regeneration of forest in abandoned farm land/ degraded forest and secondary forests.

1.3.5 Estimation of emission of methane from solid waste was done for both landfill and open dumping disposal.

- landfill estimation was restricted to Bangkok metropolitan, other municipalities, and sanitary districts.
- the open dumping methane emission estimation was restricted to the Bangkok metropolitan area only, since only quantities of waste open dumped in Bangkok are large enough to lead to emission.

1.3.6 Estimation of emission of methane from wastewater was done for both municipal and industrial wastewaters (such as pulp & paper, food industries, starch, rubber, oil & fat, canneries, slaughterhouses, etc.).

CHAPTER II

LITERATURE REVIEW

2.1 Greenhouse Effect

The greenhouse effect is a scientifically-proven natural process that is essential to maintaining the planet's climate. The term refers to the insulating effect produced by several important gases in the earth's atmosphere i.e. carbon dioxide, methane, nitrous oxide, other trace gases and water vapour.

Surrounding the earth like a giant greenhouse (see Figure 2.1 below), these gases allow short-wave solar radiation to pass through to the earth's surface where it is absorbed. The gases then trap some of energy radiated by the earth. This energy heats the earth's surface and the lower atmosphere.

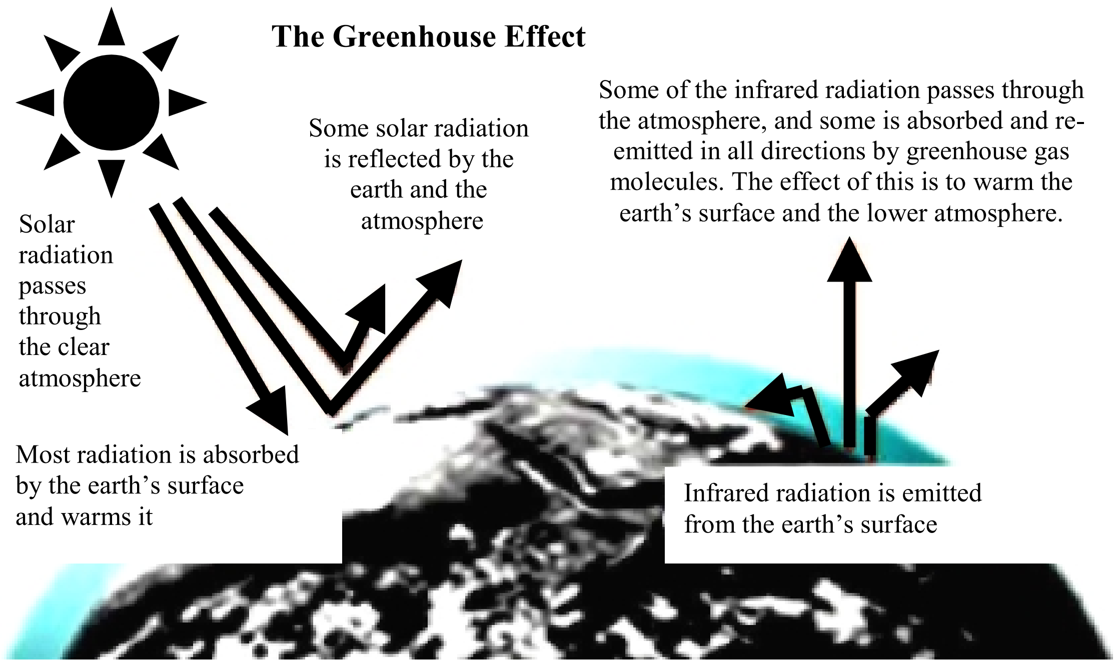


Figure 2.1 A simplified diagram illustrating the greenhouse effect (United States Environmental Protection Agency [EPA], http://www.epa.gov/oppeoee1/globalwarming/kids/greenhouse.html, 2000).

Without these ”greenhouse gases”, the heat would escape into space and the planet would be a frigid lifeless word (about 33^{o}C colder). They keep the earth’s surface and lower atmosphere comfortably warm with a global average surface temperature of 15^{o}C and maintain the proper moisture levels (British Columbia Ministry of Environment, Land & Parks, http://www.elp.gov.bc.ca/epd/epdpa/ar/clima -te/gccasu.html, 2000).

2.2 Greenhouse Gases

Greenhouse gases (GHGs) are found naturally in the atmosphere, in small quantities. They absorb outgoing long wave infrared radiation, of heat energy, which the earth and the atmosphere normally radiate back to outer space. Greenhouse gases make the earth warm and inhabitable. The major GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

CO_2 is emitted through the combustion of fossil fuels, as well as deforestation, whereas the growth of trees and forests absorbs this gas and transforms it into plant biomass. The latter process can be referred to as carbon sequestration, and is one of the only effective ways to reduce carbon dioxide in the atmosphere. Methane is usually generated form the decomposition of organic matter under oxygen deficient conditions. Waterlogged paddy fields, with less oxygenated soil, enhance the production of CH_4. In addition, enteric fermentation of ruminant animals favors CH_4 production through the digestion of feed aided by microbial activities. Wastewater treatment, sanitary landfill are also precursors of CH_4. Other than by natural processes, nitrous oxide is emitted into the atmosphere through the use of nitrogen fertilizers.

2.2.1 Carbon Dioxide (CO_2)

The greenhouse gas scientists are most concerned with is carbon dioxide. This gas is responsible for about 60% of enhanced greenhouse effect. This is due to its large in crease in atmospheric concentration (from 280 to about 360 ppmv) and long atmospheric lifetime (50-200 years). Carbon dioxide concentration in the atmosphere has risen by about 30% since preindustrial time. By comparison, carbon dioxide level appear to have varied by less than 10% during the 10,000 years before industrialization.

Projected levels of carbon dioxide in the atmosphere are higher than any observed over the past 160,000 years. If carbon dioxide emission are maintained at or near current levels, its concentration in the atmosphere would approach 500 ppmv by the end of the 21st century and would continue to increase slowly for several hundred years. Studies suggest that in order for atmospheric concentrations to stabilize below 750 ppmv, human emissions must eventually decline relative to today's levels (University of Nebraska-Lincoln, http://pw2.netcom.com/~kmgenius/ ge2ases.html, 2000).

2.2.2 Methane (CH_4)

Methane is the second most important greenhouse gas. It is estimated to be twenty-one times more effective at tripping heat in the atmosphere than carbon dioxide over a hundred-year time period. However, it has a much lower concentration in the atmosphere and atmospheric lifetime. The atmospheric level of methane has risen from 700 to about 1720 ppbv since preindustrial times. This represents about a 145% increase. The atmospheric lifetime of methane is above twelve to seventeen years.

If current emissions were held constant, methane concentrations would stabilize in the atmosphere in less than fifty years at about 1900 ppbv. A reduction in emissions of about 10% is needed for methane to stabilize at today's levels (University of Nebraska-Lincln, http://pw2.netcom.com/~kmgenius/ge2ases.html, 2000).

2.2.3 Nitrous Oxide (N_2O)

Nitrous oxide is also an important greenhouse gas. It is better at trapping heat than both carbon dioxide and methane and has comparable atmospheric lifetime to the long-lived carbon dioxide. However, its sources are relatively moderate and its concentration in the atmosphere is low. The atmospheric level of nitrous oxide has risen from 275 to about 310 ppbv since preindustrial times (about 13%). It is estimated to be 310 times more effective at trapping heat in the atmosphere than carbon dioxide over a hundred-year time period. Its atmospheric lifetime is about 120 years.

If emissions were held constant at today's levels, the nitrous oxide abundance would climb from 311 to about 400 ppbv over several hundred years. To stabilize nitrous oxide in the atmosphere at current levels, a reduction in emissions of about 50% is needed (University of Nebraska-Lincoln, http://pw2.netcom.com ~kmgenius/ ge2ases .html, 2000).

2.3 Eccentric Global Temperature

In 1997, the Intergovernmental Panel on Climate Change (IPCC) comprising 2,500 scientists from 150 countries and environmental preservation academics, industrialists as well as government representatives reported that man is the cause of global warming. The study confirmed that in 1996 and 1997 the world witnessed a record heat due to greenhouse effect because of continuously rising carbon dioxide emission into the climate. The emission of 7,000 tons of CO_2 per year rises global temperature by 4-5^{O}C worldwide and increases seawater level by 1-1.5 meters in the 21st century, including the impact from very cold and very warm weather and floods in the areas that have never encountered before (The Petroleum Authority of Thailand, 2000).

Scientists also found that the ice at the poles have started melting and when digging deep underground in the North Pole, e.g., at Fairbanks in Alaska, underground temperature was also higher. What's so strange is that in 1997 every region of the world got warmer except in the East Coast of North America, the Mediterranean and China where the weather got cooler. It was assumed that in these areas more sulfur dioxide was emitted and covered the climate; the sunray was thus reflected back to the climate.

Though no information is confirmed yet what will happen if global warming continues, right now the seawater is higher by 10 inches in the average. The IPCC forecast that it would be 12 inches higher in 2050 and 23 inches in 2100. This will make the USA lose 10,000 square miles of its coastal areas and if the seawater is 2 feet higher, the Smith Island in Serpic Gulf where islanders still speak Elizabethan English will be drowned. Beaches at Monnouth County in New Jersey and the Long Island in New York before 2050 will be shrunken by 100 feet (TEI, 1997).

2.4 Disasters from Changing Global Temperature

Scientists evaluated by using space model on the assumption that if CO_2 volume in the world climate in 2100 doubles over the present level, average surface temperature will be 1 to 3.5^{O}C, and seawater level will rise by 15-95 centimeters. This will affect the ecological system and infrastructure of man. It is expected that one-third of forests all over the world will drastically change in terms of hereditary especially in the high latitude areas while the currently ice-covered areas will lose by half in the next 100 years. As for damage to people on the land, there will be 46 million people per year at present who have to risk flooding because of waves and if seawater level gets 1 meter higher, the number of flood-risked people will be as high as 118 million, especially those small-island nations (IPCC, 1990, quoted in The Petroleum Authority of Thailand, 2000).

Right now some trends have occurred in developed countries in the west. Changing temperature has shortened winter, making it warmer with more rain while summer, on the other hand, is longer and drier, resulting in population relocation. Dams and flood prevention walls have been built while technology of plant production must be improved. In tropical and semi-tropical areas, mostly located by developing countries, it is expected that temperature should be higher than the developed ones. Very arid areas will degrade soil quality more quickly, thereby affecting agricultural methods and ecological system.

2.5 Global Warming Potential (GWP)

Greenhouse gases vary in atmospheric lifetime, and in radiative effects, also known as Global Warming Potentials. GWP defines the warming effect caused by a unit mass of a given gas relative to that of CO_2. It is estimated, for example, that in one hundred years time frame, the GWP of CH_4 and N_2O are 21 and 310 respectively. This means that a tonne of CH_4 has warming effect equivalent to 21 tonne of CO_2 and tonne of N_2O is equivalent to 310 tonne of CO_2. Table 2.1 below presents the GWP of the most recent GWPs (assigned in 1996) for the most important greenhouse gases.

Table 2.1 The GWP of the most recent GWPs (assigned in 1996).

Gas (100 Years)	GWP
CO_2	1
CH_4	21
N_2O	310

Source: IPCC (1996b).

In certain cases, the gases may be presented in units of million of metric tones of carbon equivalent (MMTCE). Carbon comprises 12/44 of carbon dioxide by weight. In order to convert emissions reported in teragrams (Tg) of greenhouse gas to MMTCE, the following equation can be used:

$$\text{MMTCE} = (\text{Tg of gas}) \times (\text{GWP}) \times (12/44)$$

2.6 Greenhouse Gases Emission in Thailand

The three most important greenhouse gases that are largely emitted in Thailand are CO_2, CH_4, and N_2O (TEI, 1997). In 1990, the emission of these gases were:

- CO_2, 164 million tonne
- CH_4, 2.8 million tonne (58 million tonne of CO_2 equivalent)

- N_2O, 0.01 million tonne (3 million tonne of CO_2 equivalent)

The three sectors, which emitted the largest quantities of greenhouse gases were energy, forestry and agriculture. Table below presents the emission quantities of GHGs in million tonne CO_2 equivalent.

Table 2.2 Greenhouse gases contribution to the warming effect by sector in Thailand in 1990.

Sectors	Emission in CO_2 equivalent (Million tonnes)	Percentage of Total Emission (%)
All Energy	79	36
Industrial Process	10	4
Agriculture	54	24
Land Use Change & Forestry	78	35
Waste	3	1
Total	225	100

Source: TEI (1997).

2.7 Greenhouse Gases Related Researches in Thailand

According to Korakotjintanakarn P. (1998), electricity generation causes large emission of CO_2 in Thailand. Fuels used in electricity generation are fuel oil, diesel oil, natural gas, lignite and imported coal. If it is assumed that combustion of the fuel is complete, the amount of CO_2 emitted from electricity-generating sector in 1990 was 24.841 million tonne and 64.967 million tonne in 2010 or 0.575 and 0.486 kg-CO_2/dWh in 1990 and 2010, respectively. CH_4 emission from production of natural gas and lignite was 1.594 million tonne of CO_2 equivalent in 1990 and 3.390 million tonne of CO_2 equivalent in 2010, respectively.

TEI (1997) estimated the national greenhouse gas inventory of Thailand for 1990 used the 1995 Guidelines of IPCC as a reference. The estimation showed that the three sectors which emitted the largest quantities of greenhouse gases in Thailand were energy (79 million tonne of CO_2 equivalent), forest (78 million tonne of CO_2 equivalent) and agriculture (54 million tonne of CO_2 equivalent), respectively.

Kessmanee C. (1997) investigated different industrial processes that have high potential to emit the greenhouse gases. The following eleven categories of industries were evaluated: cement production, lime production, glass, paper, steel, petrochemical, bakery, brewery and automobile coating. The quantities of greenhouse gases were determined using two approaches: the emission factor values provided by the IPCC method and the material balance method. The results showed that in 1990 the total emissions of CO_2, CH_4 and VOC were 16.39 million tonne, CH_4 315 tonne and VOC 122 tonne. The total greenhouse gases emission in 2001 has been predicted to be 39 million tonne of CO_2 852 tonne of CH_4 and 346 tonne of VOC.

Pongprayoon P. (1998) estimated the quantity of greenhouse gases emission from forestry sector in Thailand by using the 1996 IPCC methodologies. The estimation of greenhouse gases from forestry sector for the year 1994 showed that the total carbon storage was 1,519 Tg-C. The CO_2 emission from forestry and land use change was 10.65 Tg-CO_2/yr, and the sequestration of CO_2 was 7.23 Tg-CO_2/yr. Non-CO_2 trace gases emission of CH_4, CO, N_2O, NO_X were 11.39 Tg-CH_4/yr, 99.67 Tg-CO/yr, 0.08 Tg-N_2O/yr and 2.83 Tg-NO_X/yr, respectively.

Samkgahn K. et al. (2000) mentioned different CH_4 emissions factors for Thailand which were derived by different researchers according to them, the range of seasonal emissions for irrigated rice, rainfed rice, deep water were 0.45-75.00 g/m^2, 1.90-71.00 g/m^2 and 4.9-63.00, respectively.

CHAPTER III
METHODOLOGY

In order to achieve the objectives, this study followed the research methodology as illustrated in Figure 3.1. It started from formulation of GHGs emission estimation and collection of all relevant information. The major information sources for this study are:

- Bank of Thailand
- Department of Energy Development and Promotion (DEDP)
- Department of Livestock Development
- Department of Pollution control
- Factory Control Division
- Forest Industries Organization (FIO)
- Industrial Control Division
- International Energy Agency
- Intergovernmental Panel on Climate Change (IPCC)
- King Mongkut University of Technology Thonburi (KMUTT)
- Office of Agriculture Statistics
- Office of Environmental Policy and Planning
- Office of National Statistics
- Thai Plywood Industry Co., Ltd (TPL)
- Thailand Environment Institute (TEI)
- Thailand Development Research Institute (TDRI)
- Other published information (from inside and outside of Thailand)

Consequently, the GHGs emission from five sectors: Energy, Industrial Processes, Agriculture, Forest, and Waste was carried out. Analyses of the calculation results include comparison of GHGs emission in Thailand between 1990, 1995 and 1998; and comparison of emissions among selected countries. Improvement and

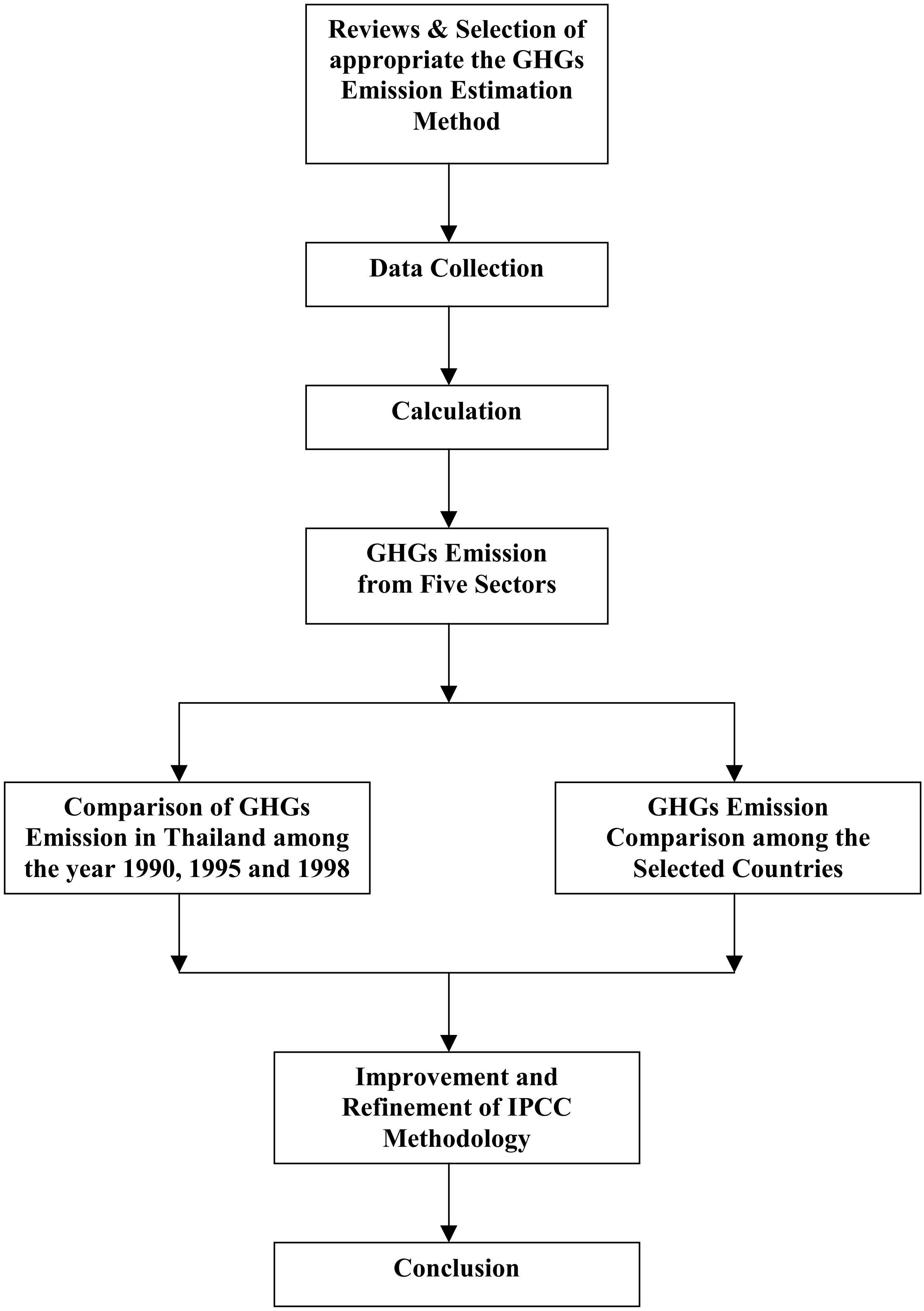


Figure 3.1 Flow diagram for this study

refinement of the estimation methodology in this study was summarized and discussed. Finally, all major findings were concluded in the next chapter of this thesis.

Various emission sectors of greenhouse gases are presented in Figure 3.2. The methods for estimating their emissions are discussed in the remaining of this chapter.

3.1 Estimation of Greenhouse Gases Emission from Energy Sector

Greenhouse gas emission from the Energy sector is classified into two main categories. Those are fuel combustion emission and fugitive emission. In this studied, estimation method for energy sector is based on the IPCC methodology (1996a) for Thailand.

3.1.1 Estimation of CO_2 and Non-CO_2 from Fuel Combustion

Fossil Fuel. Fossil fuel combustion is the burning of coal, oil or natural gas used to generate energy. Of these, coal contains the highest amount of carbon per unit energy and natural gas contains the least. Common sources of fossil fuels consumption include different transport, steam production for industrial processes, heating in residential and commercial buildings and the generation of electricity. Fossil fuel combustion may also release unburned hydrocarbons, methane and carbon monoxide. The estimation of the CO_2 as well as non-CO_2 from fossil fuels can be done using the following method.

The IPCC methodology approach to estimate CO_2 emissions requires the estimation of apparent consumption of the fossil fuels and is calculation as follows:

Fuel apparent consumption = production + imports - exports - international bunkers - stock change

Apparent consumption is converted from physical to common energy units by using local conversion factors. This study uses the specific unit of calorific joules. The carbon content of fuels is then evaluated from the total apparent consumption (tera-joule, TJ unit) multiplied by carbon emission coefficients (t-C/TJ).

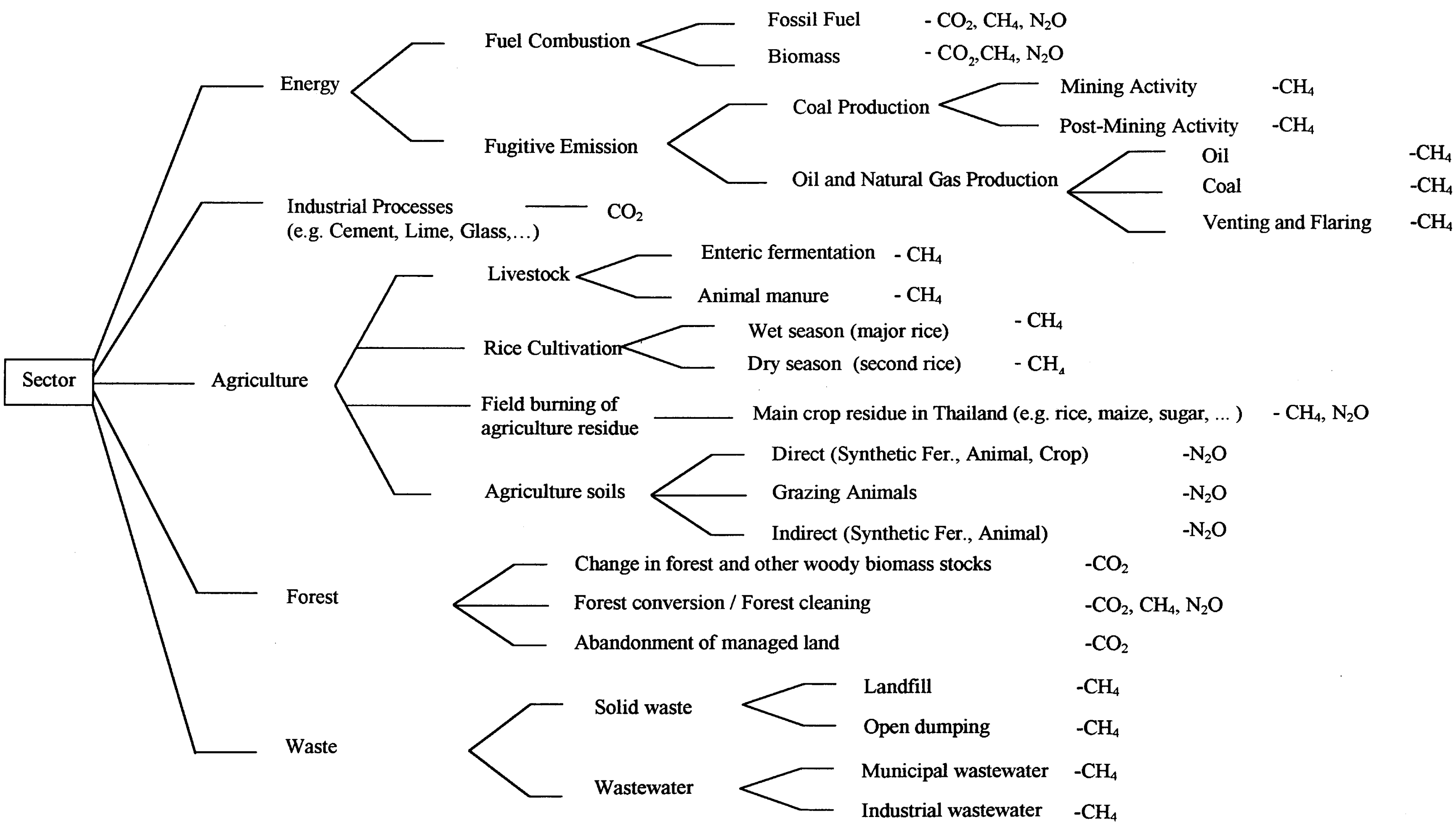


Figure 3.2 The flow chart of the different sectors and their greenhouse gases emission.

Carbon dioxide is derived using the molecular weight ratio of the carbon dioxide and carbon element. The equation can be calculated as follows.

Apparent Consumption (TJ) = apparent consumption (Physical Units) $\times$ conversion factor (TJ/Physical Units)

Carbon dioxide emission = [total carbon content (Gg-C) - total carbon stored (Gg-C)] $\times$ fraction of carbon oxidised (by fuel type) $\times$ 44/12

where

Total carbon content (Gg-C) = Σ apparent consumption (by fuel type in TJ) $\times$ carbon emission factor (by fuel type in t-C/TJ) $\times 10^{-3}$

Total carbon stored (Gg-C) = non-energy use (10^3 t) $\times$ conversion factor (TJ/10^3 t) $\times$ emission factor (t-C/TJ) $\times$ fraction of carbon stored $\times 10^{-3}$

To calculate sector-wise emission of CO_2 the following formula can be used:

Carbon emission = [(Σ fuel consumption expressed in energy units (TJ) for each sector $\times$ carbon emission factor) – carbon stored] $\times$ fraction of carbon oxidized

For non-CO_2 such as CH_4, N_2O etc., the following formula can be used:

$$\text{Emission} = \Sigma\,(EF_{abc} \times \text{activity}_{abc})$$

where EF represents the emission factor (g/GJ), activity is the energy input (GJ), and subscripts a, b, and c represent fuel type, sector activity, and technology type, respectively.

Biomass. Biomass burning is the burning of organic non-fossil material such as trees and plants for energy production. Biomass burning also releases significant amounts of CO_2 and non-CO_2. Total carbon released from the biomass combustion can be determined from the quantity of the biomass consumed (dry basis) multiplied by the carbon fraction in the fuel and the fraction of carbon oxidized in burning. Thus,

Total carbon dioxide (Gg-CO_2) = total carbon released (Gg-C) × 44/12

where

Carbon released from biomass fuel (Gg-C) = total biomass consumed (kt-dry matter)
× carbon fraction × fraction oxidized
× 1 Gg/kt-dry matter

For non-CO_2 estimation from biomass, the formula as in case of fossil fuel can be used.

3.1.2 Fugitive Emission

Emission of GHGs from various energy production activities is termed "fugitive emission" in the IPCC Greenhouse Gas Inventory Reference Manual (1996b). 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 leakage in the processes of extraction, storage and transmission to end-users. Therefore, leakage of any gas components, which have a low molecular weight, for example methane and volatile organic carbon (VOC), are more likely to occur.

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

Coal Production. Coal is mainly carbon, 40-98% depending on the type, with much smaller amounts of water and sulphur and trace amounts of radioactive materials found on the earth. There are three types of coal that have been formed: lignite (brown coal), bituminous coal (soft coal) and anthracite (hard coal). As coal ages, its carbon content increases and its water content decreases. Currently coal provides about 25% of the world's commercial energy and at current consumption level coal will last at least another 300 years.

In a coal-fired power plant, large amount of coal are pulverized to fine dust and then burned at very high temperatures. The heat converts purified water continuously running through the tubes into a high-pressure steam, which spins the shaft of a turbine. When coal is burned at very high temperature it releases different types of air pollutant, such carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides, lead, arsenic, nickel, cadmium and particulate matter (fly ash). In 1990, the total world CO_2 emission due to coal combustion was 2.382 Gt-C/year and the corresponding figure in 1993 was 2.240 Gt-C/year (International Energy Agency [IEA], http:// www1.klc.lu.se/iiiee/sources/energy/energy_home.html, 2000a).

Estimations of emission of non-CO_2 was done according to the equations set out below.

- Coal Mining Activities

Annual coal production is multiplied by a global emission factor. The IPCC provides both low and high emission factors. The equations used are as follows:

Minimum emission of CH_4 (Gg) = low CH_4 emission factor (m^3-CH_4/tonnes of coal mined) $\times$ surface coal production (Mt) $\times$ conversion factor (Gg/10^6 m^3)

Maximum emission of CH_4 (Gg) = high CH_4 emission factor (m^3-CH_4/tonnes of coal mined) $\times$ surface coal production (Mt) $\times$ conversion factor (Gg/10^6 m^3)

- Post-Mining Activities

The equation used is as follows:

Surface CH_4 emission (Gg) = CH_4 emission factor (m^3-CH_4/tonnes of coal mined)
$\times$ surface coal production (Mt)
$\times$ conversion factor (Gg/10^4 m^3)

Oil and Natural Gas Production. Methane is the most important greenhouse gas emitted from all oil and natural gas production. Conventional natural gas is found above most reservoirs of crude oil. It consist a mixture of 50-90% by volume of methane, small amounts of heavier gaseous hydrocarbons such as ethane, propane and butane and highly toxic hydrogen sulfide. Natural gas is also found in unconventional deposits. When a natural gas field is tapped, propane and butane gases are liquefied and removed as liquefied petroleum gas (LPG).

Like other fossil fuels, natural gas is burned to convert its chemical energy to electric energy, but it has less environmental impact as compared to other types of fossil fuels. Burning gas produces 43% less carbon dioxide per unit of energy than coal and 30% less than oil. In 1990, the total world CO_2 emission due to gas combustion was 2.639 Gt-C and the corresponding figure in 1993 was 1.086 Gt-C (International Energy Agency [IEA], http://www1.klc.lu.se/iiiee/sources/energy/ene-rgy_home.html, 2000).

Estimations of emissions of non-CO_2 GHG was calculated according to the equations set out below.

- Oil Production

Fugitive methane emission (Gg-CH_4) = oil production (PJ)
$\times$ emission factor from the specified region (kg/PJ) $\times$ conversion factor (10^{-6} Gg/kg)

- Oil Refining

Fugitive methane emission ($Gg\text{-}CH_4$) = oil production (PJ) × emission factor from the specified region (kg/PJ) × conversion factor (10^{-6} Gg/kg)

- Natural Gas Production

The general equation for determining fugitive losses from natural gas production is

Fugitive methane emissions ($Gg\text{-}CH_4$) = natural gas production (PJ) × emission factor (kg/PJ) × conversion factor (10^{-6} Gg/kg).

3.2 Estimation of Greenhouse Gases Emission from Industrial Processes Sector

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. The inventory presented here describes emissions from the following industrial processes such as cement production, lime manufacturing, glass production, pulping process, steel production, bread production, beer production, whisky production and wine production.

Greenhouse gas emission factors were derived from the mass balance approach (TEI, 1997; Kessmanee C., 1997). Finally, the emission factors for each process were converted into weight ratios of CO_2 per production output as shown in Table 3.1 below.

Table 3.1 The emission factors for each industrial process.

Industry	Emission Factor ($t\text{-}CO_2$/t-Production)
Cement	0.4985
Glass	0.2026
Lime	0.7857
Pulp & Paper	0.2072
Iron and Steel	0.0099
Bakery	1.4670
Beer	0.0272
Wine	0.0815
Whisky	0.2718

Source: Kessmanee C. (1997).

Specific processes like beer brewing will also be included in this study. In beer production CO_2 is generated in the fermentation process and is captured and reused to carbonate the beer for consumption although CO_2 is still eventually release back into the atmosphere

Once the emission factor is known, the general equation to determine the quantity of CO_2 emitted followed IPCC (1996a) for Thailand.

$$CO_2 \text{ emission (t)} = \text{physical units of production (e.g., t)} \times \text{emission factor (e.g., t-}CO_2\text{/t-product)}$$

3.3 Estimation of Greenhouse Gases Emission from Agriculture Sectors

3.3.1 Livestock Sector

The primary greenhouse gas emission from livestock is methane, which is derived from feed digestive processes, mainly in ruminants and from animal manure. Enteric fermentation in herbivores produces methane as a by-product of the digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the blood stream. Both ruminant animals (e.g. cattle, buffalo) and some non-ruminant animals (e.g., pigs, horses) produce methane, but ruminants are the largest source.

Methane emission from enteric fermentation and from animal manure was estimated according to IPCC methodology (1996a). The estimation approaches for different animal type in this study are shown in Table 3.2. Group 1 refers to animal with small population and Group 2 refers to large population.

Methane production from the enteric fermentation process will be calculated in the following way:

$$E_f = \sum (\text{animal population}_n \times EF_{fn})$$

where E_f represents methane emission volume (kg/yr), EF_f represents enteric fermentation emission factor for animal 'n', and animal population is average population of animal type 'n' (head/yr).

Table 3.2 Methods use to estimate methane emission from various animal types.

Animal Types	Enteric Fermentation	Manure
Dairy cattle, Non-dairy cattle, Buffalo	Group 2	Group 2
Goat, Sheep, Horse	Group 1	Group 1
Swine	Group 1	Group 2
Poultry		Group 1

In this study, the enteric fermentation emission factor (EF_f) for Group 1 followed IPCC methodology (1996a) for Thailand. For large population, emission factors for each type of animal was calculated from the energy intake and methane conversion rate as follows:

$$EF_{fn}\text{ (kg/yr)} = [GE\text{ (MJ/day)} \times Ym \times (365\text{ days/yr})] / (55.65\text{ MJ/kg-}CH_4)$$

where EF_{fn} represents emission factor for animal type 'n', Ym represents methane conversion rate which is recommended as 6% by IPCC (1996b), and GE is the gross energy intake.

Methane emission from livestock manure was also estimated according to IPCC methodology (1996a). As indicated in Table 3.2, Group 1 was used to estimate fecal methane production from goats, sheep, horses and poultry while for Group 2 was applied for those from dairy cattle, non-dairy cattle, buffalo and swine.
Fecal methane emission was estimated as follows:

$$E_{iw} = \sum (\text{animal population}_i \times EF_{iw})$$

where E_{iw} represents total fecal methane emission from manure, animal population$_i$ is average population of animal 'i', and EF_{iw} represents emission factor of animal manure 'i'.

In this study, the enteric fermentation emission factor (EF_{iw}) for Group 1 in Thailand follows IPCC methodology (1996). For Group 2, fecal emission factors for each type of animal was calculated as follows:

$$EF_i = VS_i \times 365 \text{ days/yr} \times B_{oi} \times 0.67 \text{ kg/m}^3 \times \Sigma (MCF_{jk} \times MS\%_{ijk})$$

where EF_i represents emission factor (kg/yr) for animal type 'i', VS_i represents volatile solid produced (kg/day) for animal 'i', B_{oi} represents methane producing capacity (m^3/kg of VS) for manure produced by animal 'i', MCF_{jk} represents methane conversion factor for manure management system 'j' by climate region 'k' and $MS\%_{ijk}$ represents fraction of animal type 'i' under manure system 'j' by climate region 'k'.

3.3.2 Rice Cultivation Sector

Thailand is one of the world's major rice producing countries. The estimated methane emission in the report of TEI (1993, quoted in Siriratpiriya O., 1997) for crop year 1989 ranged from 2.34 to 8.49 Tg-CH_4/year that is equivalent to 5.66 to

9.36% of methane emission from Rice Cultivation in the world. Figure 3.3 shows the relationship of CH_4 in rice cultivation.

According to IPCC methodology (1996a), methane emission from paddy fields can be estimated using the following equation:

$$F = \sum_{i} \sum_{j} \sum_{k} EF_{ijk} A_{ijk} T_{ijk}$$

where 'EF' is the emission rate of methane (Tg/ha/day), 'A' is paddy area (ha) and 'T' is seasonal cropping period (day). Subscripts 'i', 'j' and 'k' represent water regimes (irrigated, rainfed, deep water and dry), fertilizer applications and cropping periods (depending on rice cultivars), respectively.

3.3.3 Field Burning of Agriculture Residue Sector

The estimation of greenhouse gases emission from on site burning of agricultural residues is base on the total carbon released which is a function of the amount and efficiency of biomass burning and the carbon content of the biomass. Non-CO_2 gas emissions are estimated by applying the emission ratios of CH_4 and CO to the total carbon released and the emission ratios of N_2O and NO_X to the total nitrogen released.

According to IPCC methodology (1996a), GHGs emission from field burning of agriculture residue can be estimated using the following equation:

Total carbon released (tonnes of C) = ∑ harvested area (ha)
× productivity figure (t/ha)
× average dry matter content of crop residue
× fraction actually burnt in the field
× fraction oxidized
× the carbon fraction of crop residue

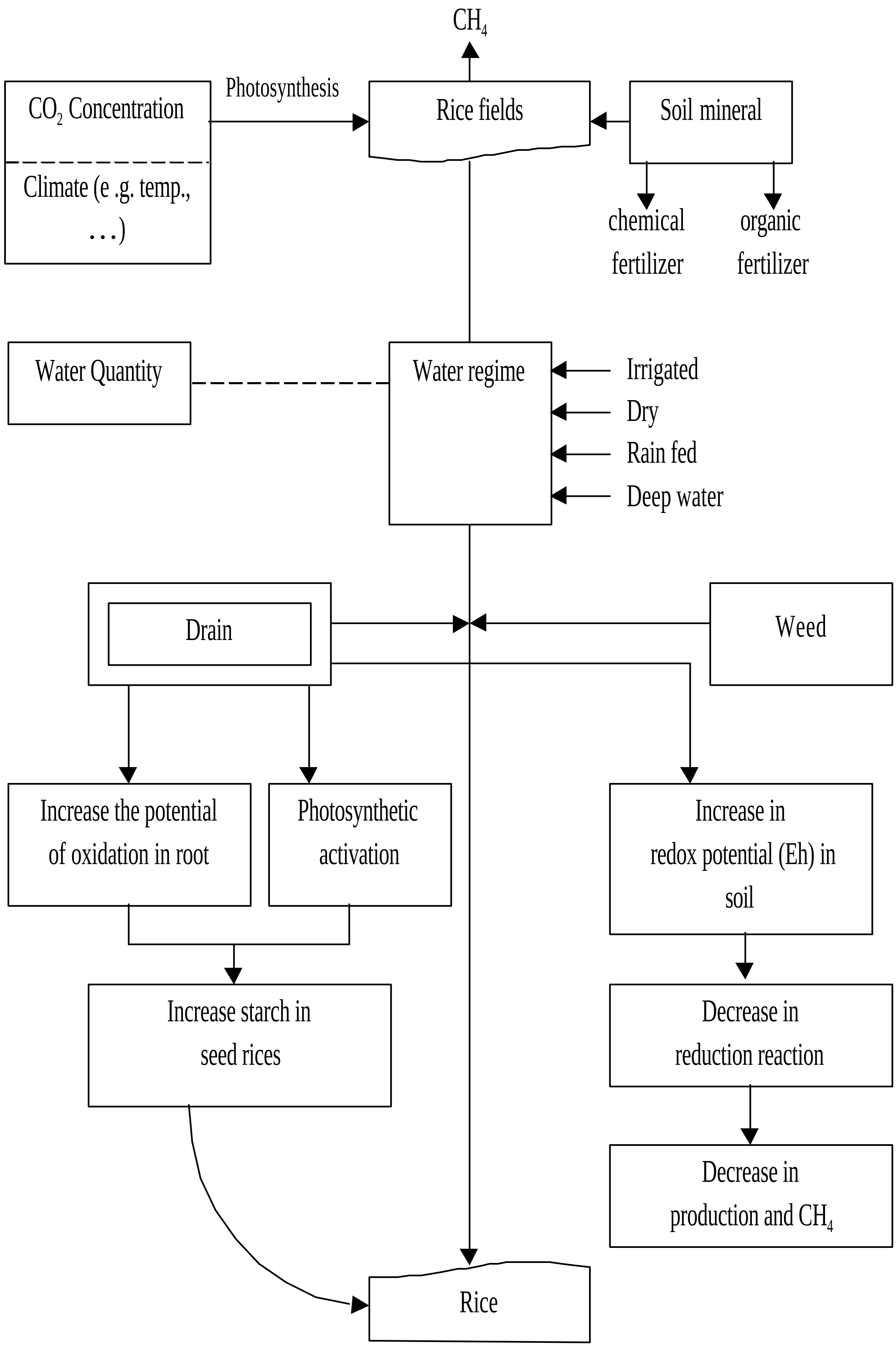


Figure 3.3 The relationship of CH_4 in rice cultivation (Sirirutpiriya O., 1997).

To estimate the emission of CH_4 and CO, the amount of carbon released due to burning is multiplied by the emission ratios of CH_4 and CO relative to total carbon to yield emissions of CH_4 and CO (each expressed in units of C). Emissions of N_2O and NO_X, first the total carbon released is multiplied by the estimated N/C ratio of the fuel by weight to yield the total amount of nitrogen (N) released. The total N released is then multiplied by the ratios of emission of N_2O and NO_X relative to the N content of the fuel to yield emissions of N_2O and NO_X (expressed in units of N).

3.3.4 Agriculture Soils Sector

Cultivated soils produce N_2O, a very potent greenhouse gas. The emissions of N_2O depend mainly on the amount of synthetic of 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 fractions volatilized from cultivated soils and from also formation of N_2O from leached or contaminated groundwater.

According to IPCC methodology (1996a), GHG emission from agriculture soils can be estimated using the following equation:

$$N_2O_{Direct} = (F_{SN} + F_{AW} + F_{BN} + F_{CR}) \times EF_1$$

where

EF_1 = emission factor for direct soil emissions (0.0125 kg-N_2O-N/kg-N input)

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)

$$N_2O_{Grazing\ Animal} = \sum [N_{(T)} \times Nex_{(T)} \times Frac_{Graz\ (T)} \times EF_2]$$

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)

$Frac_{Graz\,(T)}$ = fraction of $Nex_{(T)}$ that is released in one of the different grazing animal of type T in the country

EF_2 = N_2O emission factor for animal waste excreted in pastures (0.02 kg-N_2O-N/kg of Nex)

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

where

$N_2O_{(G)}$ = N_2O emission from volatilization of NO_X and NH_3

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

3.4 Estimation of Greenhouse Gases Emission from Forest Sector

Estimations of greenhouse gases emission from Forest and Land-Use Change are most complicated and usually controversial due to complex biological factors, lack of reliable data and adverse human impacts. Methodologies used in this study to estimate greenhouse gases from forest follows the TEI approach (1997) which was improved from IPCC methodology (1995).

Thus, emission of CO_2 primarily from activities related to the utilization and replanting of trees and forest was estimated. Natural forests were considered to be carbon neutral. Therefore, they are neither sources nor sinks of carbon. The study involves:

(a) changes in forest and other woody biomass stock which includes emission and sequestration of C by the following activities: (i) uptake of C by biomass from the growth of trees through reforestration and afforesstation. (ii) emission of C from biomass from harvesting timber in plantation forest and fuel wood consumption.

(b) forest conversion/forest clearing includes carbon emission from deforestation or forest clearing through the following activities: (i) burning of above ground biomass on site. (ii) decaying of timber biomass utilized off site, and (iii) decomposition of above ground biomass on site.

(c) estimation of emission of non-CO_2 trace gases, such as CH_4 and N_2O from on-site burning of plant residues after deforestation.

(d) abandonment of managed land includes sequestration of C into plant biomass resulting from the natural regeneration of forest in abandoned farm land/ degraded forest and secondary forests.

A source is anything that causes an increase in the concentration of greenhouse gases in the atmosphere. It can be direct or indirect. Sinks are reservoirs that take in more of a certain kind of gas than they release, thereby reducing the concentration of the gas in the atmosphere. Forest act as CO_2 sinks mainly because they contain photosynthetic organisms that consume large amounts of CO_2 during growth. The overall photosynthetic process consists of the formation of carbohydrates by the reduction of CO_2,

$$nCO_2 + nH_2O \xrightarrow{\text{light}} (CH_2O)_n + nO_2$$

where $(CH_2O)_n$ is a shorthand for any carbohydrate. The essence of the process is the use of photochemical energy to split water and hence to reduce CO_2.

3.4.1 Change in Forest and Other Woody Biomass Stocks

- Net CO_2 flux from plantation forest or managed forest

$$Cn = (Cs - Cr) \times 44/12$$

where

44/12 = Factor for conversion C to CO_2

- Annual biomass C removal

$$Cr = \sum_{f} [(RW_f \text{ x } EF) + FW_f + OW_f - FC_f] \times CP_f$$

where

Cr = Annual biomass C removal

RW = Round wood harvest (m^3/yr)

EF = Biomass conversion / expansion ratio (m^3/t-dm)

FW = Annual fuel wood consumption (t-dm/yr)

OW = Other wood uses (t-dm/yr)

FC = Wood removed from burning off site (t-dm/yr)

CP = C fraction in plantation or planted species (t-C/t-dm)

f = Forest types

dm = Dry matter

- Annual biomass C uptake

$$Cs = \sum_{f} (AP_f \times GP_f \times CP_f)$$

where

Cs = Annual biomass C uptake (t-C/yr)

AP = Area of plantation and managed forest (ha)

GP = Annual biomass growth rate (t-dm/ha/y)

CP = C fraction in plantation or planted species (t-C/t-dm)

3.4.2 Forest Conversion/Forest Clearing

- Total CO_2 released from forest conversion

$$FC = (C_{ab} + C_{agb}) \times 44/12$$

where

FC = Total CO_2 released from burning of above ground biomass (t-CO_2/yr)

C_{ab} = Total C released from burning of above ground biomass (t-C/yr)

C_{agb} = Total C released from decomposition of above ground biomass on site(t-C/yr)

C_{df} = Total C released from decomposition of timber biomass off site (t-C/yr)

- C released from burning of above ground biomass

$$C_{ab} = (C_{bn} + C_{bf})$$

where

C_{bn} = Amount of C released by on site burning (t-C/yr)

C_{bf} = Amount of C released by off site burning (t-C/yr)

- C released from burning of above ground biomass on site

$$C_{bn} = \sum_{f} [A_f \times (BB_f - BA_f) \times FBn_f \times FOn_f \times C_f]$$

where

C_{bn} = C released from burning of above ground biomass on site (t-C/yr)

A = Area of forest cleared in the inventory year (ha/yr)

BB = Biomass density before clearing (t-dm/ha)

BA = Biomass density after clearing (t-dm/ha)

FB_n = Fraction of biomass burnt on site

FO_n = Fraction of biomass oxidized on site

C = C fraction (t-C/t-dm)

- C release from burning of above ground biomass off site

$$C_{bf} = \sum_{f} [A_f \times (BB_f - BA_f) \times FBf_f \times FOf_f \times C_f]$$

where

C_{bf} = C released from burning of above ground biomass off site (t-C/yr)

A = Area of forest cleared annually (ha/yr)
BB = Biomass density before clearing (t-dm/ha)
BA = Biomass density after clearing (t-dm/ha)
FBf_f = Fraction of biomass burnt off site
FOf_f = Fraction of biomass oxidized off site
C = C content in biomass (t-C/t-dm)

- Total C released by decomposition of above ground biomass

$$C_{agb} = \sum_{f} [A_f \times (BB_f - BA_f) \times FD_f \times C_f]$$

where
C_{agb} = C released by decomposition of above ground biomass (t-C/yr)
BB = Biomass density before forest clearing (t-dm/ha)
BA = Biomass density after forest clearing (t-dm/ha)
FD = Fraction of biomass left to decay
C = C fraction in biomass (t-C/t-dm)

CH_4 and N_2O from on site burning of plant residues after deforestation were calculated according to the equation set out below.

- Methane (CH_4) emissions from biomass burning

$$F_{CH_4} = AC \times ER_{CH_4} \times 16/12$$

where
F_{CH_4} = Emissions of CH_4, from biomass burning (t-CH_4/yr)
AC = Annual C released from on site burning
ER_{CH_4} = Emission ratio

- Total N released from biomass burning

$$FN = AC \times NC$$

where

FN = Total annual N released (t-N/yr)

AC = Annual C released from on site burning

NC = N/C ratio (default value = 0.01)

- Nitrous oxide (N_2O) emissions

$$F_{N_2O} = FN \times ER_{N_2O} \times 44/28$$

where

F_{N_2O} = Emission of N_2O from biomass burning (t-N_2O/yr)

FN = Total N released (t-N/yr)

ER_{N_2O} = Emission ratio

3.4.3 Abandonment of Managed Land

- Annual C uptake in above ground biomass

$$C_{BR} = \Sigma (AY \times RB \times C)$$

where

C_{BR} = Annual C uptake in above ground biomass (t-C.yr)

AY = Total area abandoned and regrowth

RB = Annual rate of above ground biomass accumulation (t-dm/ha/yr)

C = C fraction of biomass (t-C/t-dm)

3.5 Estimation of Greenhouse Gases Emission from Waste Sector

The most important gas produced in this source category is methane (CH_4) that produced and released in to the atmosphere is a by-product of the anaerobic decomposition of waste. Two major sources of this type of CH_4 production are solid waste disposal to land and wastewater treatment. This study followed the IPCC methodology (1996a) for estimation.

3.5.1 Emission from Solid Waste

- Municipal solid waste landfill can be calculated using the following equation:

$$\begin{aligned}\text{Methane emission (Gg/yr)} = \text{total MSW (Gg/yr)} &\times \text{MSW landfill fraction}\\ &\times \text{DOC fraction in MSW}\\ &\times \text{actual DOC fraction dissimulated}\\ &\times 0.55 \text{ g-C as } CH_4\text{/g-C in biogas}\\ &\times \text{conversion ratio } (16/12)\end{aligned}$$

where MSW is municipal solid waste and DOC is degradable organic carbon.

- Municipal solid waste open dumping can be calculated using the following equation:

$$\begin{aligned}\text{Methane emission (Gg/yr)} = \text{total MSW (Gg/yr)} &\times \text{MSW opendumping fraction}\\ &\times \text{DOC fraction in MSW}\\ &\times \text{actual DOC fraction dissimulated}\\ &\times 0.275 \text{ g-C as } CH_4\text{/g-C in biogas}\\ &\times \text{conversion ratio } (16/12)\end{aligned}$$

3.5.2 Emission from Wastewater

- Municipal wastewater can be calculated using the following equation:

Methane emission rate (Gg/yr) = population × wastewater BOD value
(Gg-BOD/person/yr) × fraction treated anaerobically
× 0.22 Gg-CH_4/Gg-BOD

- Industrial wastewater can be calculated using the following equation:

Methane emission rate (Gg/yr) = sum of BOD generated by industry and treated
Anaerobically (t-BOD/year)
× 0.22 Gg-CH_4/Gg-BOD

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Estimation of Greenhouse Gas Emissions from the Five Sectors

The three most important greenhouse gases which are largely responsible for contributing to global warming are CO_2, CH_4 and N_2O. The major sources of emission of these gases in Thailand are: Energy, Industrial Processes, Agriculture, Forest, and Waste sectors. Estimation of different greenhouse gases from these sources in Thailand has been made using appropriate and available data, and appropriate methodologies as described in Chapter III. The results of the GHGs estimation of each sector are presented and discussed below. Summary of the results and example of calculation worksheets are presented in Appendices C and D, respectively.

4.1.1 Energy

Greenhouse gases are emitted from the Energy sector through two main activities: fuel combustion and fugitive emission. Fuel combustion mainly releases CO_2, with minimal amounts of CH_4 and N_2O from burning of fossil fuels by different sub-sectors. This activity is caused by power, transport, industry, agriculture, and residential & commercial sub-sectors. Fugitive emission includes emission of CH_4 during the production of coal, and oil and natural gas. In Thailand, types of fossil and bio-mass fuels, such as gasoline, jet kerosene, diesel oil, residual oil, LPG, anthracite, coking coal, briquette & other coal, lignite, natural gas, wood, charcoal, paddy husk and bagasse, were used by the above mentioned sub-sectors (Power, Agriculture, Residential & Commercial, Industry, Mining & Construction, and Transport) (Department of Energy Development and Promotion, 1991). The energy consumption data are presented in Appendix E.

(i) Fuel combustion. Figure 4.1(a) presents the emission of CO_2 from fuel combustion activities by different sub-sectors in 1990. The total CO_2 emissions from the combustion of fuels was 120 million tonne. As the largest consumer of fuel, Transport emitted the largest share of CO_2 (28.7%), followed by Industry, Mining & Construction (26.4%), and Power (23.5%). When combined, these three sub-sectors emitted more than 78% of the total CO_2 emissions.

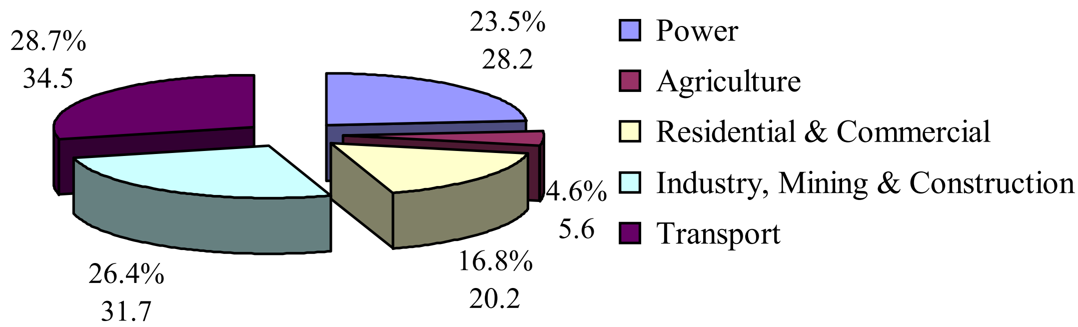
Figure 4.1(b) presents the emission of CO_2 from fuel consumption activities by different sub-sectors in 1995. It is noticed that total CO_2 emissions from the combustion of fuels amounted to 205 million tonne, which is an increase of 71% from the year 1990. Transport, and Industry, Mining & Construction sub-sectors were the largest emitters (55.2% of the total emission of CO_2).

Figure 4.1(c) presents the emission of CO_2 from fuel consumption activities by different sub-sectors in 1998. The total CO_2 emissions from the combustion of fuels was 193 million tonne. In this year, Power sub-sector emitted the largest share of CO_2 (30.1%), followed by Transport (29.6%), and Industry, Mining & Construction (25.5%). CO_2 emissions decreased in many sub-sector from 1995 to 1998, however, the emission in Power sub-sector increased 11%.

From 1990 to 1995, the contributions to CO_2 emission from different sub-sectors have little change. In 1998, the contribution changed in many sub-sectors. In addition to Power sub-sectors emitted the largest share (30% of the total emission of CO_2), the share from Residential & Commercial sub-sector (11.8% of the total emission of CO_2) decreased from the year 1990 and 1995.

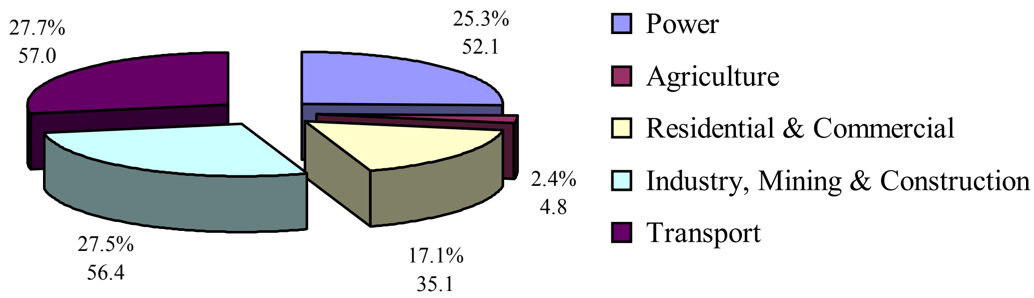
Figures 4.2 & 4.3 shows the emission of CH_4 and N_2O in 1990, respectively. The dominant emitter of CH_4 was Residential & Commercial sub-sector (85% of total emission of CH_4). In case of N_2O, Industry, Mining & Construction, and Residential & Commercial sub-sectors were the two largest emitters (68% of the total emission of N_2O).

Total Emission = 120.1 million tonne



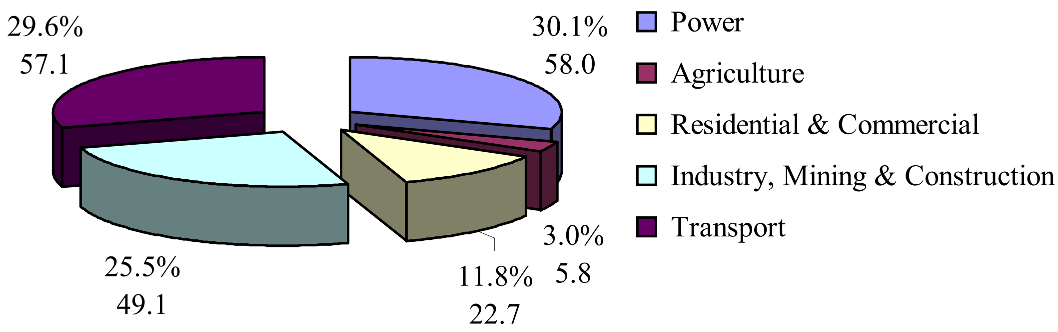
(a)

Total Emission = 205.3 million tonne



(b)

Total Emission = 192.6 million tonne



(c)

Figure 4.1 Emission of CO_2 from fuel combustion activities by different sub-sectors in: (a) 1990, (b) 1995, and (c) 1998 (in million tonne and percent).

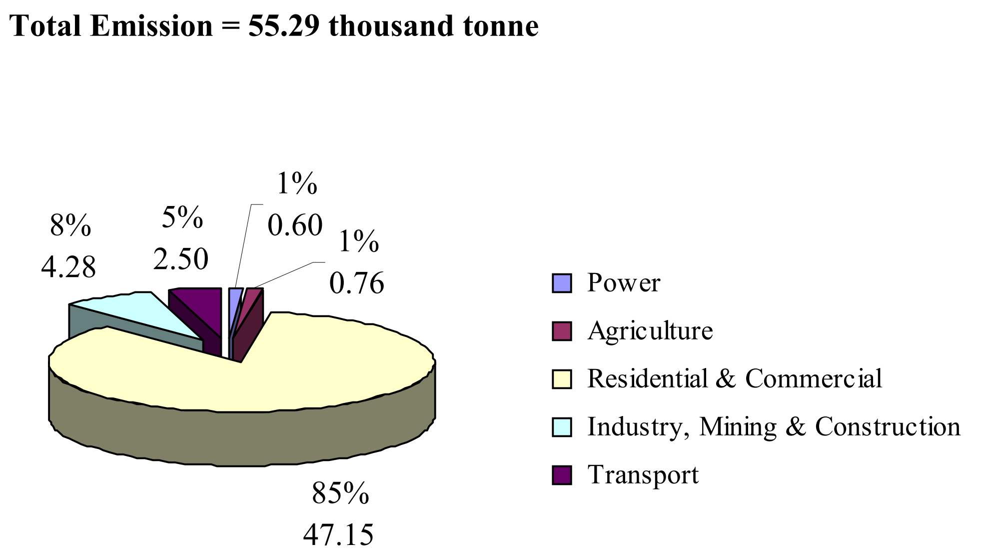


Figure 4.2 Emission of CH_4 from fuel combustion by different sub-sectors in 1990 (in thousand tonne and percent).

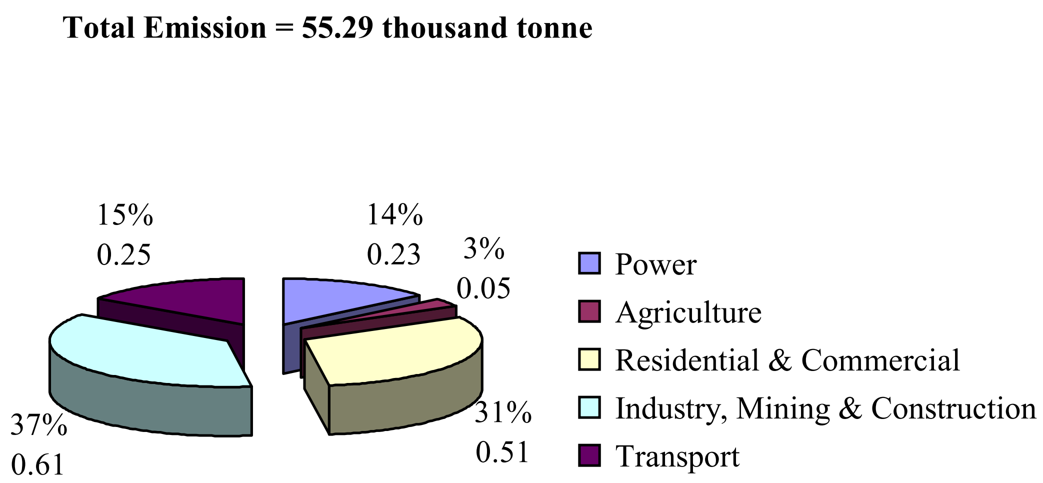


Figure 4.3 Emission of N_2O from fuel combustion by different sub-sectors in 1990 (in thousand tonne and percent).

Figures 4.4 & 4.5 show the emission of CH_4 and N_2O in 1995, respectively. The two largest emitters of CH_4 were Residential & Commercial and Industry, Mining & Construction sub-sectors (93% of total emission of CH_4). In case of N_2O, Industry, Mining & Construction, and Residential & Commercial sub-sectors were the two largest emitters (68% of the total emission of N_2O).

Figures 4.6 & 4.7 shows the emission of CH_4 and N_2O in 1998, respectively. The main emitters of CH_4 were still Residential & Commercial and Industry, Mining & Construction sub-sectors (90%). In case of N_2O, Industry, Mining & Construction, and Residential & Commercial sub-sectors were the largest emitters (63% of the total emission of N_2O). Therefore, in all three studied years, the contributions from five sub-sectors to CH_4 and N_2O emissions changed only slightly.

(ii) Fugitive emission. Figure 4.8(a) shows the fugitive emission of CH_4 from fuels in 1990. The CH_4 emissions from solid fuel, i.e. coal, as well as oil and gas production activities were estimated at around 104 thousand tonne. The majority of fugitive emission (90%) came from oil and natural gas production activities.

Figure 4.8(b) shows the fugitive emission of CH_4 from fuels in 1995. The CH_4 emissions form coal mining as well as oil and gas production activities were estimated at 185 thousand tonne.

Figure 4.8(c) shows the fugitive emission of CH_4 from fuels in 1998. Total CH_4 emissions from fugitive emission were estimated at 280 thousand tonne. It is noticeable that CH_4 emissions from oil and natural gas production activities increased 55% from the year 1995.

Although total emissions of CH_4 increased through the three studied years, the contribution to CH_4 emission had little change. The majority of fugitive emission activities (more than 90%) came from oil and natural gas production activities.

Total Emission = 91.40 thousand tonne

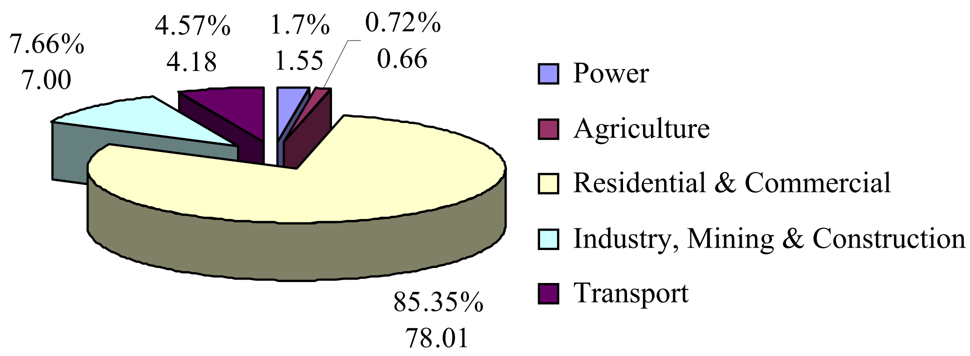


Figure 4.4 Emission of CH_4 from fuel combustion by different sub-sectors in 1995 (in thousand tonne and percent).

Total Emission = 2.57 thousand tonne

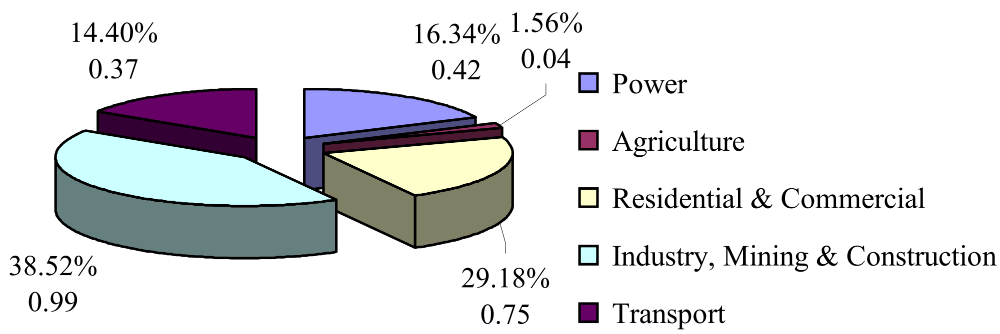


Figure 4.5 Emission of N_2O from fuel combustion by different sub-sectors in 1995 (in thousand tonne and percent).

Total Emission = 63.37 thousand tonne

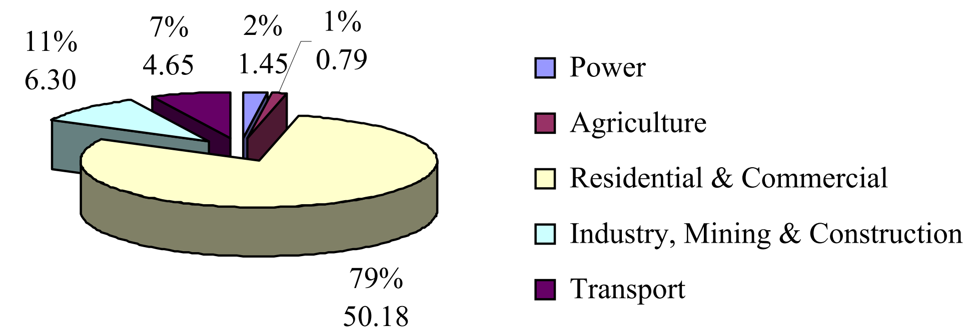


Figure 4.6 Emission of CH_4 from fuel combustion by different sub-sectors in 1998 (in thousand tonne and percent).

Total Emission = 2.27 thousand tonne

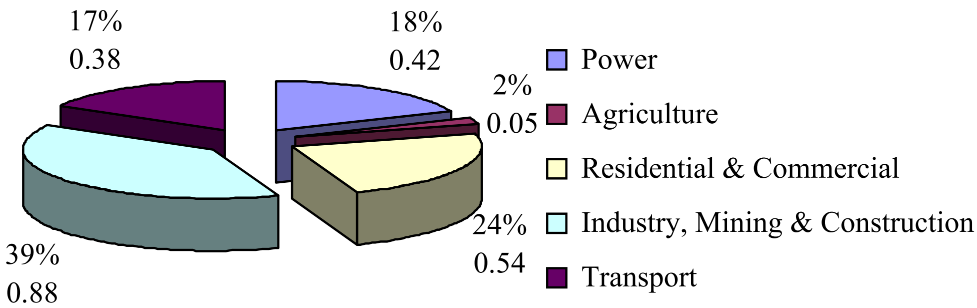


Figure 4.7 Emission of N_2O from fuel combustion by different sub-sectors in 1998 (in thousand tonne and percent).

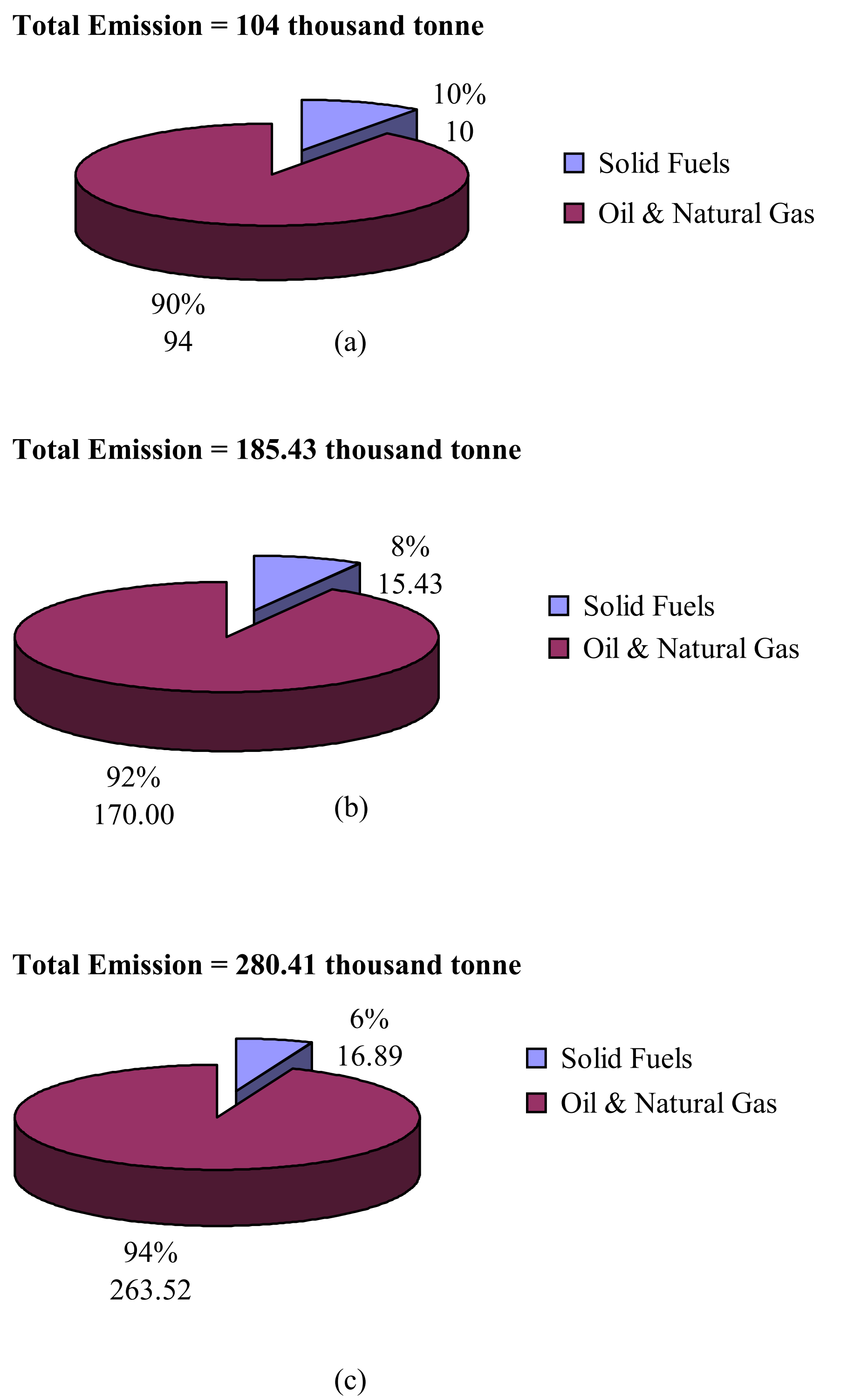


Figure 4.8 Emission of CH_4 from fugitive emission by type of fuels produced in: (a) 1990, (b) 1995, and (c) 1998 (in thousand tonne and percent).

4.1.2 Industrial Processes

The emissions of greenhouse gas from Industrial Processes are not from the energy related activities, but occur through the production processes. The type of greenhouse gases emitted depends on the nature of the manufacturing processes, quantities of raw material consumed, chemical reaction, and the conversion efficiency of the compound outputs. The major types of industry in Thailand that emit greenhouse gas from there manufacturing processes are cement, glass, lime, paper pulp, iron & steel, bread, beer, wine and whisky. The industrial production data of these industries in Thailand and a detail of calculation are presented in Appendix D.

Table 4.1 presents the emission of CO_2 from industrial processes in different industries. In 1990, Industrial Processes sector emitted a total of 9 million tonnes of CO_2 where cement industry contributed the vast majority of CO_2 emission. In 1995, Industrial processes sector emitted a total of 18 million tonnes of CO_2 where cement industry contributed the 97% of total CO_2 emission. Finally, in 1998, Industrial processes sector emitted a total of 11 million tonnes of CO_2 where cement industry contributed 94% of CO_2 emission.

Table 4.1 CO_2 emission (thousand tonne) by different industries in 1990,1995, and 1998.

Industry	1990		1995		1998	
	CO_2 Emissions	%	CO_2 Emissions	%	CO_2 Emissions	%
Cement	9002	96	16974	97	11327	94
Glass	44	0.47	94	0.53	77	0.64
Lime	72	0.77	121	0.69	98	0.82
Paper & Pulp	32	0.34	62	0.35	144	1.20
Iron & Steel	8	0.09	20	0.11	14	0.12
Bread	15	0.16	19	0.11	20	0.17
Beer	7	0.08	18	0.10	27	0.22
Wine	24	0.26	40	0.23	48	0.40
Whisky	170	1.81	230	1.31	249	2.07
Total	9375	100	17578	100	12004	100

Although total CO_2 emissions increased through three years, the contribution to CO_2 emission of different industries had little change. The majority of the emission came from cement production, while the rest has minor contribution.

4.1.3 Agriculture

Emissions of greenhouse gas from sub-sectors in Agriculture sector are CH_4 from Rice Cultivation and Livestock (including enteric fermentation and manure management), N_2O from Agriculture Soils and Field Burning of Agriculture Residue which is the result of burning of eight main crop residues such as rice, maize, sorghum, cassava, sugar cane, mungbean, soybean and groundnut in Thailand. The agricultural data describing crop production, harvested area, nitrogen fertilizer consumption and number of livestock in Thailand and detail of calculation are presented in Appendix D.

Figure 4.9 & 4.10 present the emissions of CH_4 and N_2O in 1990, respectively. The total CH_4 and N_2O emissions from Agriculture sector amounted to 3437 thousand tonne and 33.57 thousand tonne, respectively. The largest emitter of CH_4 was Rice Cultivation. Agriculture Soils was the largest emitter of N_2O in that year.

Figure 4.11 & 4.12 present the emissions of CH_4 and N_2O in 1995, respectively. It is noticed that total CH_4 and N_2O emissions from Agriculture sector amounted to 3466 thousand tonne and 38.07 thousand tonne, respectively. The largest emitter of CH_4 was Rice Cultivation. Agriculture Soils was the largest emitter of N_2O in that year.

Figure 4.13 & 4.14 present the emissions of CH_4 and N_2O in 1998, respectively. It is noticed that total CH_4 and N_2O emissions from Agriculture sector amounted to 3518 thousand tonne and 32.40 thousand tonne, respectively. Although total CH_4 emissions increased from the year 1995, CH_4 emissions from Livestock sub-sector decreased 36%. The contribution of CH_4 emissions in 1990 and 1995 were almost same. In 1998, the contribution of CH_4 emissions changed in Rice Cultivation (from 82% to 88% of total emission of CH_4) and livestock (from 18% to 11% of total emission of CH_4). In case of N_2O, Agriculture Soils sub-sector was constantly the largest emitter (99% of the total emission of N_2O) throughout the studied years.

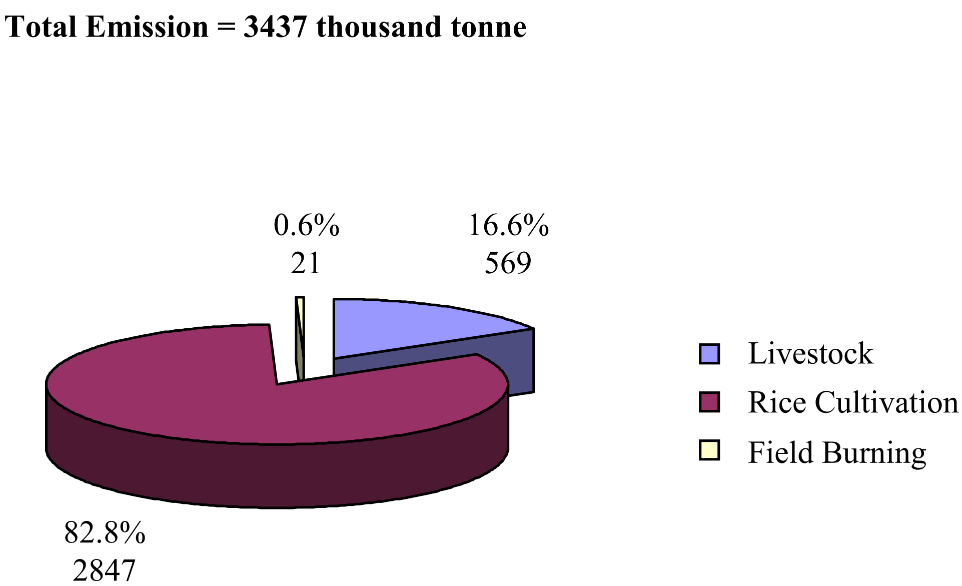


Figure 4.9 Emission of CH_4 from agriculture activities by different sub-sectors in 1990 (in thousand tonne and percent).

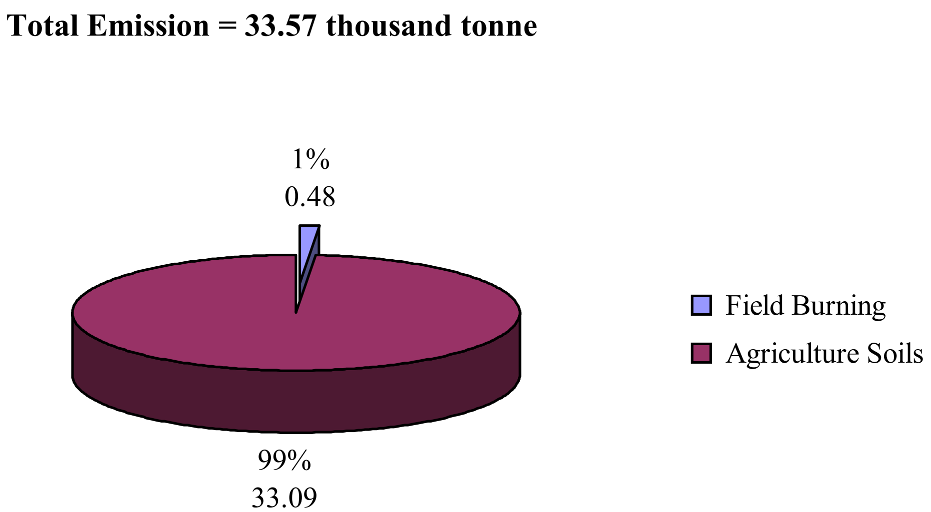


Figure 4.10 Emission of N_2O from agriculture activities by different sub-sectors in 1990 (in thousand tonne and percent).

Total Emission = 3466 thousand tonne

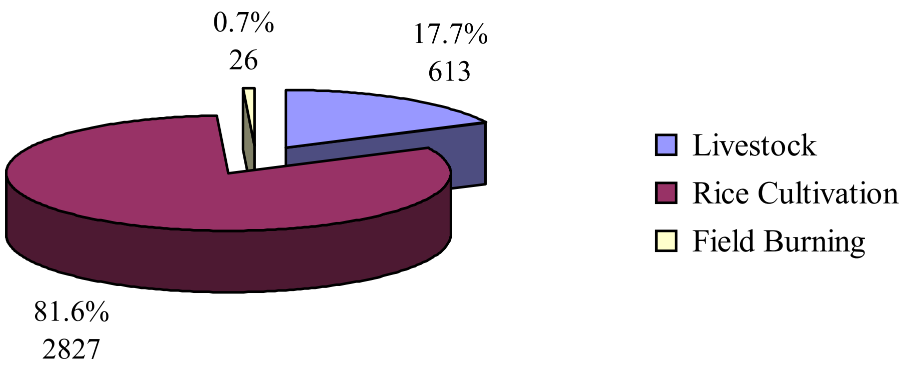


Figure 4.11 Emission of CH_4 from agriculture activities by different sub-sectors in 1995 (in thousand tonne and percent).

Total Emission = 38.07 thousand tonne

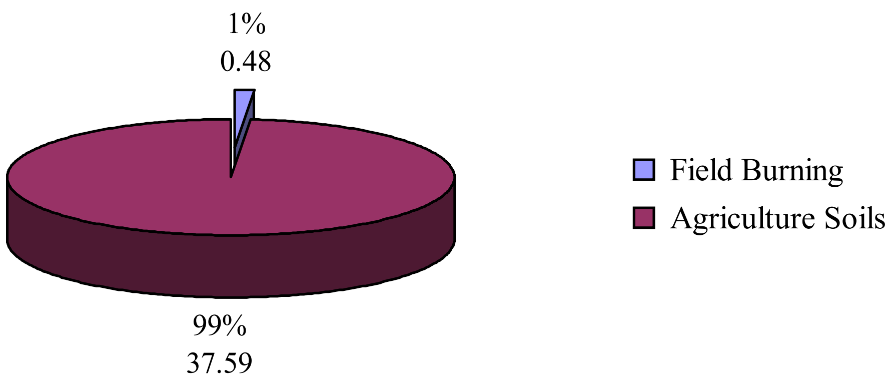


Figure 4.12 Emission of N_2O from agriculture activities by different sub-sectors in 1995 (in thousand tonne and percent).

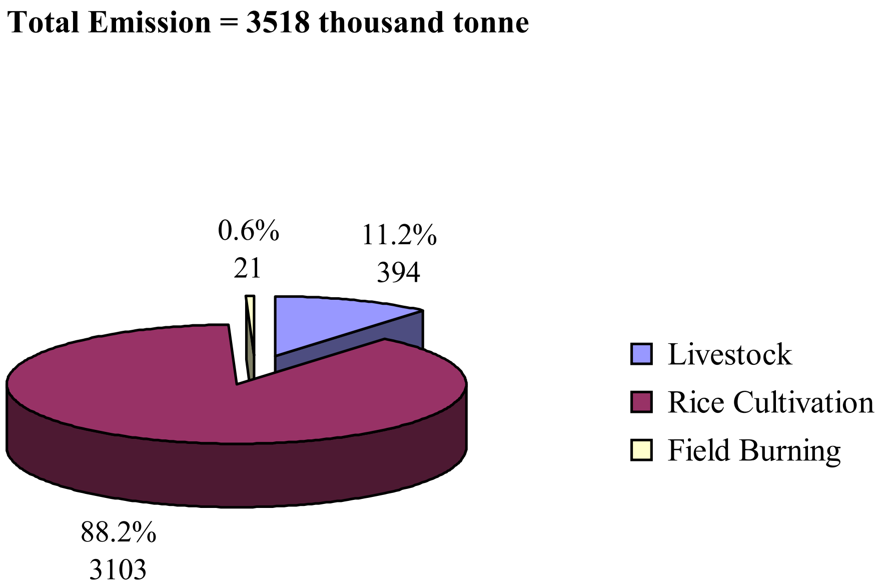


Figure 4.13 Emission of CH_4 from agriculture activities by different sub-sectors in 1998 (in thousand tonne and percent).

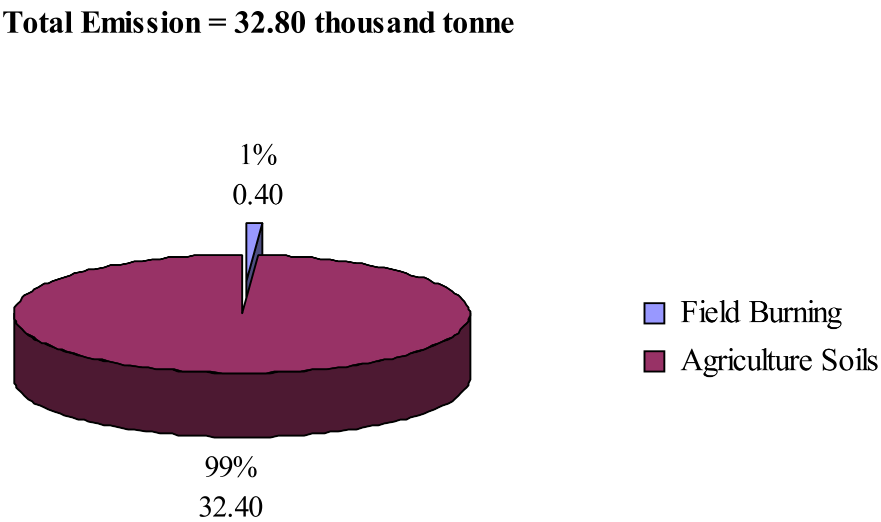


Figure 4.14 Emission of N_2O from agriculture activities by different sub-sectors in 1998 (in thousand tonne and percent).

4.1.4 Forest

Greenhouse gases are emitted from Forest sector through three main activities: (i) Change in forest and other wood biomass stocks includes emission and sequestration of CO_2 (ii) Forest conversion, including CO_2, CH_4, and N_2O emission from deforestation (iii) Abandonment of managed lands includes sequestration of CO_2 into plant biomass resulting from the natural regeneration of forest in abandoned land and secondary forests. Forest sector mainly releases CO_2, with minimal amounts of CH_4, and N_2O from on-site burning by forest conversion activitie. The forestry data of Thailand and detail of calculation are presented in Appendix D.

Table 4.2 presents the net emission of CO_2 from Forest sector by different activities in 1990. The largest emitter of CO_2 was forest conversion. There was also a remarkable sink of CO_2 by abandonment of managed lands.

Table 4.2 Net CO_2 emission from Forest sector by different activities in 1990 (in million tonne and percent).

Activities	CO_2 Emission (a)	CO_2 Removal (b)	Net-CO_2 Emission (a-b)	% of Total Emission
Change in Forest and Other Wood Biomass Stocks	29	0.9	28	24
Forest Conversion	87		87	76
Abandonment of Managed Lands		25.4	-25	-22
Total	116	26.3	90	

Table 4.3 presents the net emission of CO_2 from Forest sector by different activities in 1995. It is noticed that CO_2 emissions from forest conversion activity decreased 61% from the year 1990.

Table 4.3 Net CO_2 emission from Forest sector by different activities in 1995 (in million tonne and percent).

Activities	CO_2 Emission (a)	CO_2 Removal (b)	Net-CO_2 Emission (a-b)	% of Total Emission
Change in Forest and Other Wood Biomass Stocks	30	0.6	29	46
Forest Conversion	34		34	54
Abandonment of Managed Lands		24.2	-24	-38
Total	64	24.8	39	

Table 4.4 presents the net emission of CO_2 from Forest sector by different activities in 1998. It is noticed that CO_2 emissions from forest conversion activity decreased 47 % from the year 1995. The largest emitter of CO_2 was the Change in Forest and Other Wood Biomass Stocks activity.

Table 4.4 Net CO_2 emission from forest sector by different activities in 1998 (in million tonne and percent).

Activities	CO_2 Emission (a)	CO_2 Removal (b)	Net-CO_2 Emission (a-b)	% of Total Emission
Change in Forest and Other Wood Biomass Stocks	31	0.2	30	63
Forest Conversion	18		18	37
Abandonment of Managed Lands		22.4	-22	-46
Total	49	22.6	26	

CH_4 and N_2O that are emitted form the on-site burning by Forest Conversion activity in all three studied years, as shown in Table 4.5 are considered small compared to emissions of CO_2.

Table 4.5 CH_4 and N_2O emission (thousand tonne) from on-site burning by forest conversion activity in 1990, 1995 and 1998.

Gas	Greenhouse Gas Emission		
	1990	1995	1998
CH_4	30.94	12.07	6.64
N_2O	0.21	0.10	0.05

The contribution of CO_2 emission from Forest sector in 1990 and 1995 have a lot of changing. In 1995, the contribution of Forest Conversion activity decreasing was 37% of the total emission of CO_2 and the contribution of Change in Forest and Other Wood Biomass Stocks activity increasing was 63% of the total emission of CO_2. It is noticed that the contribution of Change in Forest and Other Wood Biomass Stocks, and Abandonment of Managed Lands activities increased through three years.

4.15 Waste

Greenhouse gases are emitted from the Waste sector through two main sub-sectors; (i) Solid waste disposal on land that emit greenhouse gas, such as CH_4 from both landfill and open dumping disposal sites. (ii) Wastewater treatment that emit CH_4 from both municipal wastewater and industrial wastewater treatment plants (anaerobic). The waste data describing quantities of waste in landfill and open dumping disposal sites, water used and number of factories in Thailand and detail of calculation are presented in Appendix D.

Figure 4.15(a) presents the emission of CH_4 from Waste sector in 1990. It is noticed that largest emitter of CH_4 in 1990 was wastewater treatment plants (anaerobic).

Figure 4.15(b) presents the emission of CH_4 from Waste sector in 1995. It is noticed that total CH_4 emissions increased 41% from the year 1990. The largest emitter of CH_4 was wastewater treatment plants (anaerobic).

Figure 4.15(c) present the emission of CH_4 from Waste sector in 1998. It is noticed that total CH_4 emissions increased 18% from the year 1995. The largest emitter of CH_4 was wastewater treatment plants (anaerobic).

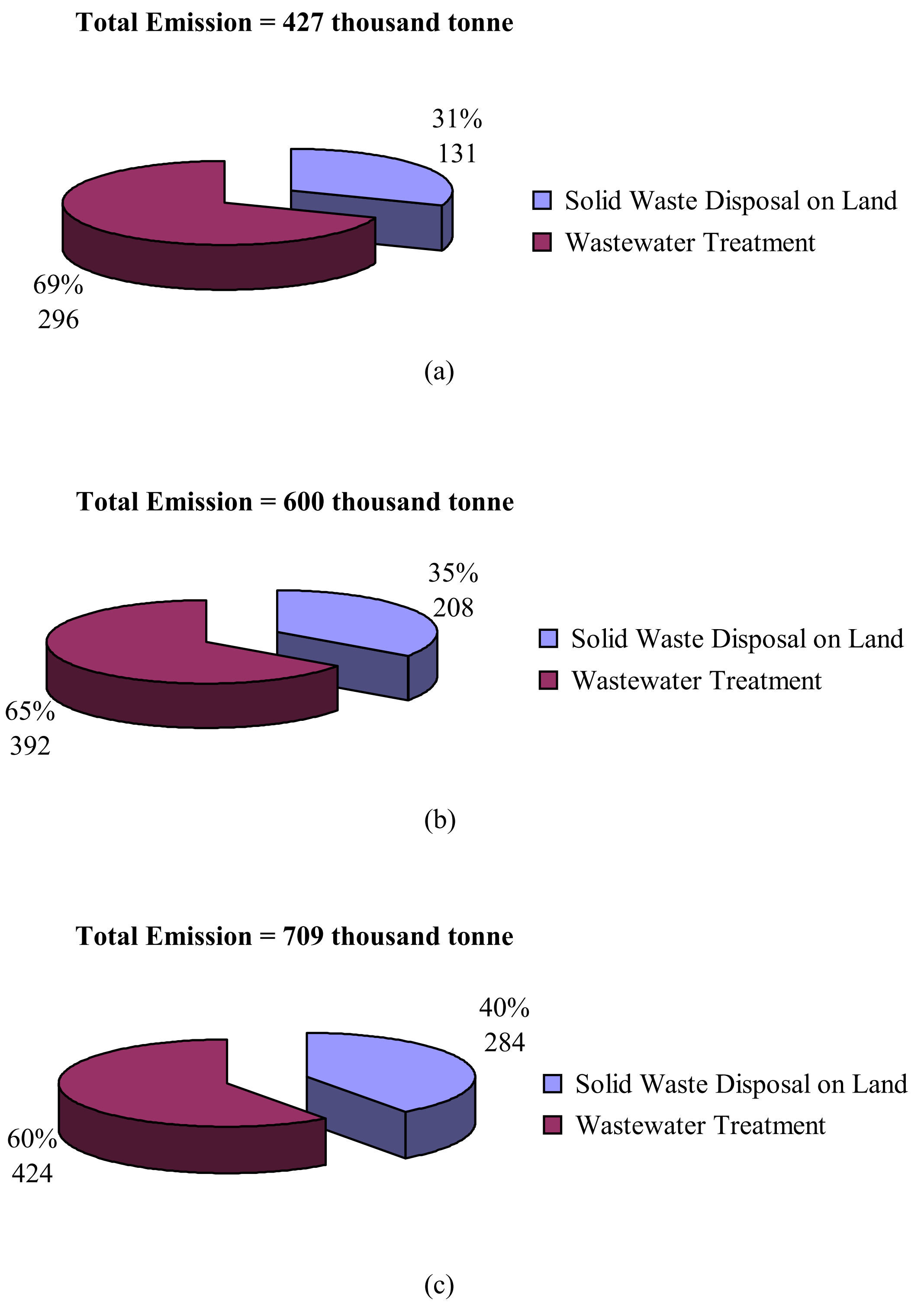


Figure 4.15 Emission of CH_4 from waste sector in: (a) 1990, (b) 1995,and (c) 1998 (in thousand tonne and percent).

4.2 Comparison of Greenhouse Gas Emission in Thailand among the year 1990, 1995 and 1998

4.2.1 Energy

(i) Fuel combustion. Figure 4.16 presents a comparison of CO_2 emission by different sub-sectors in 1990, 1995 and 1998. It is noticed that during 1990 to 1998, Transport, Industry, Mining & Construction, and Power were main sub-sectors of CO_2 emission.

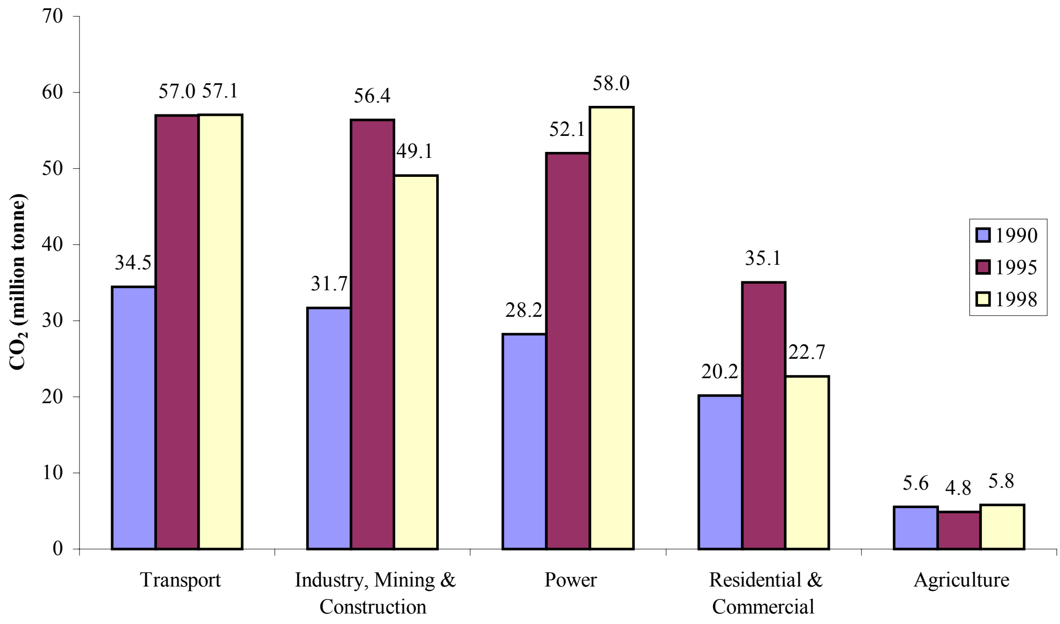


Figure 4.16 CO_2 emission (million tonne) from fuel combustion activities by different sub-sectors in 1990, 1995 and 1998.

In 1995, the total energy consumption has increased from the year 1990 (see Table 4.6). The energy used by each of these three sub-sectors increased more than 60% from the year 1990. Due to the economic recession in Thailand in 1998, the total energy consumption in that year declined from that of the year 1995.

Thailand's economy showed a negative growth rate of about 10.5% in 1998 (see Table 4.7). In 1998, almost all sub-sectors CO_2 emissions decreased, specifically residential & commercial sub-sector, which decreased 35% from the year 1995. However, power sub-sector increased 11% from the year 1995.

Table 4.6 Total energy consumption by sub-sectors (Mtoe) in Thailand.

Sub-sector	1990	1995	1998
Transport	11.4	18.8	18.9
Industry, Mining & Construction	6.8	12.4	11.1
Power	9.1	16.7	19.7
Residential & Commercial	5.3	9.1	6.0
Agriculture	1.8	1.6	1.9
Total	34.3	58.5	57.5

Table 4.7 Gross domestic product of Thailand (1990-1998) at constant 1988 prices.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Growth rate (%)	11.2	8.6	8.1	8.4	9.0	8.9	5.9	-1.4	-10.5
GDP (billion bath)	1945	2111	2283	2471	2693	2942	3115	3073	2749

Source: Kakwani N. (1999)

Table 4.8 and Figure 4.17 present a comparison of CH_4 emission by different sub-sectors. It is noticed that the Industry, Mining & Construction sub-sector was the largest contributor of CH_4 from fuel combustion activity.

Figure 4.18 presents a comparison of N_2O emission by different sub-sectors. It has been noticed that from 1990 to 1998, the largest emitters of N_2O was Industry, Mining & Construction followed by Residential & Commercial, Power and Transport sub-sectors. Among the five sub-sectors, agriculture was the lowest emitter of N_2O in three years.

In 1995, CH_4 and N_2O emission from the Industry, Mining & Construction sub-sector increased 64% and 62% from the year 1990, respectively. Its emission in year 1998 decreased because of the economic down turn, and the decreasing energy consumption.

Table 4.8 CH_4 emission (thousand tonne) from fuel combustion by different sub-sectors in 1990, 1995 and 1998.

Sub-sectors	CH_4 Emission		
	1990	1995	1998
Power	0.60	1.55	1.45
Agriculture	0.76	0.66	0.79
Residential & Commercial	47.15	78.01	50.18
Industry, Mining & Construction	4.28	7.00	6.30
Transport	2.50	4.18	4.65
Total	55.29	63.58	63.37

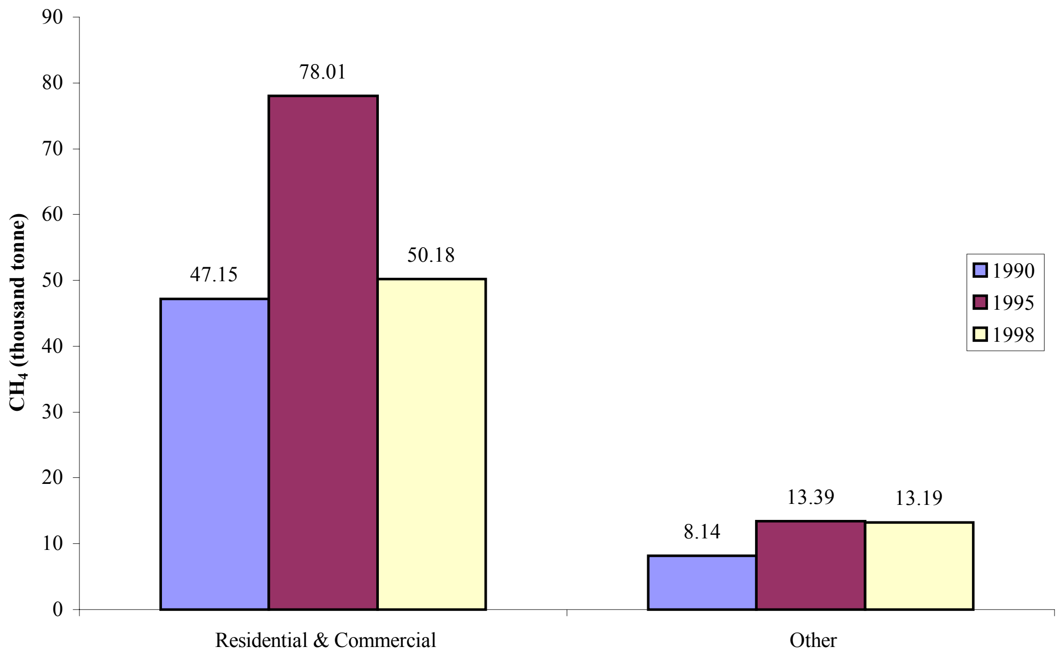


Figure 4.17 CH_4 emission (thousand tonne) from fuel combustion by different sub-sectors in 1990,1995 and 1998.

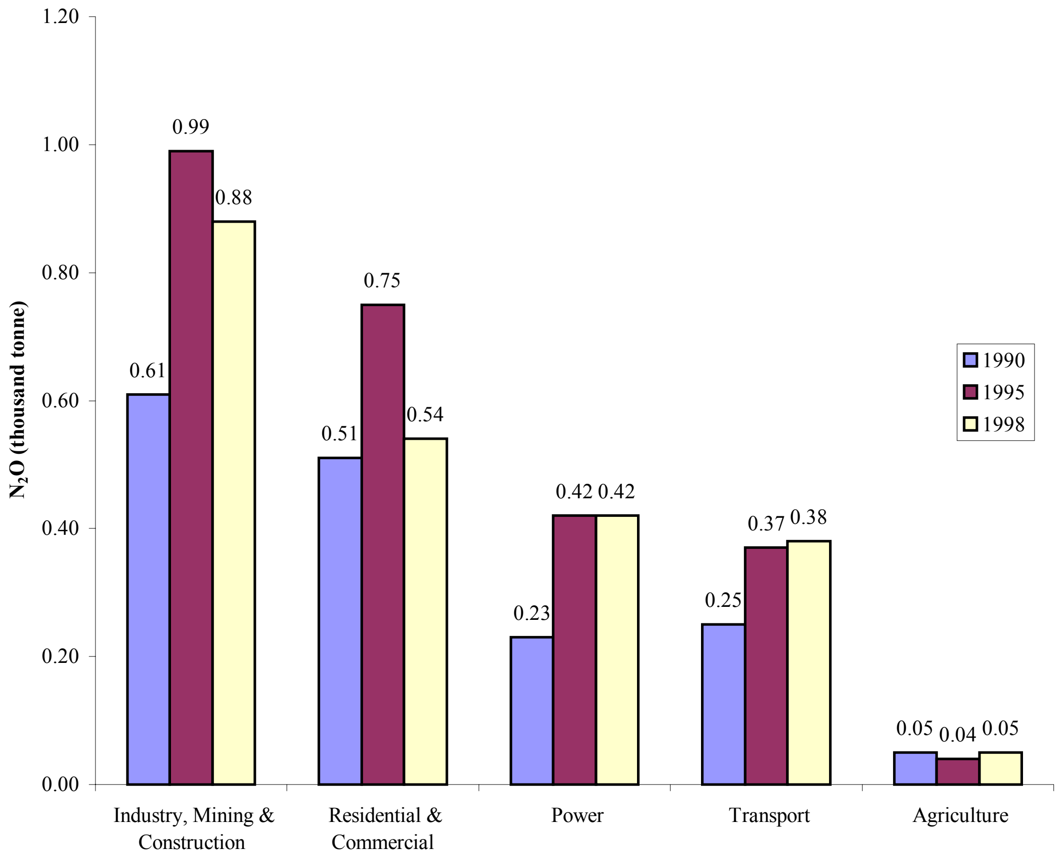


Figure 4.18 N_2O emission (thousand tonne) from fuel combustion by different sub-sectors in 1990,1995 and 1998.

(ii) Fugitive emission. Figure 4.19 shows a comparison of CH_4 emission in 1990, 1995 and 1998

Currently, the energy demand growth rate is increasing every year. It becomes a big burden for the government to provide adequate energy to meet the domestic demand (see Table 4.9). It has been noticed that CH_4 emission from fugitive emission activity emitted increased throughout the years.

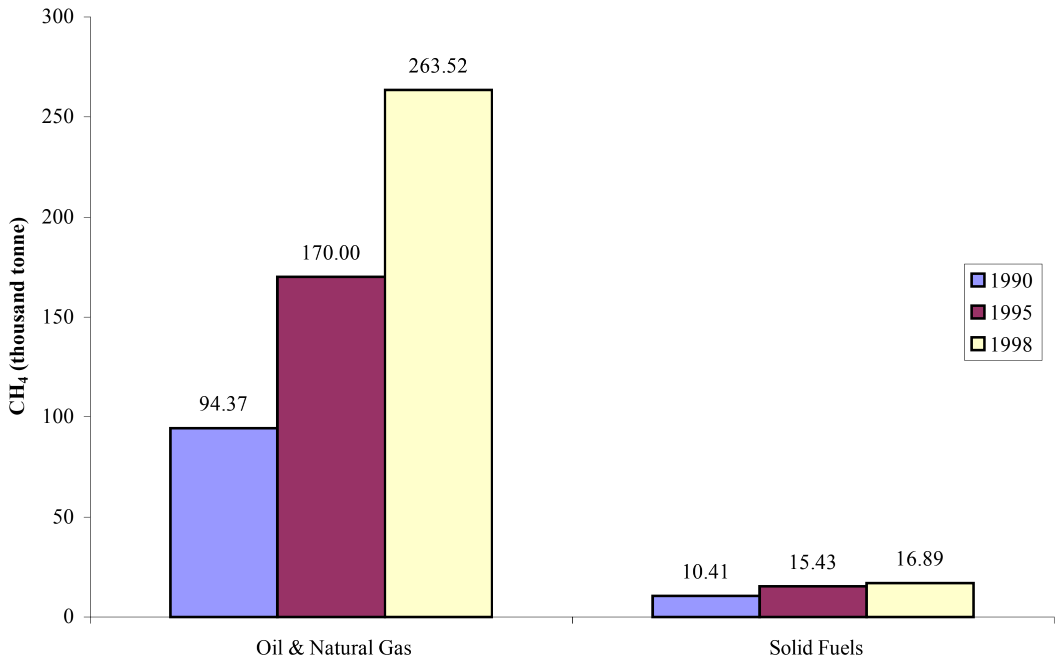


Figure 4.19 CH_4 emission (thousand tonne) from fugitive emission by fuels in 1990, 1995 and 1998.

Table 4.9 Primary energy production in Thailand (ktoe).

Fuel	1990	1995	1998
Lignite	3570	5520	6075
Crude Oil	1196	1189	1512
Natural Gas	5657	9833	15284

Source: Thailand Energy Situation (1999)

4.2.2 Industrial Processes.

The industrial sector involves the chemical or physical transformation of raw materials into intermediate and/or final product. Thus the amounts of greenhouse gas emitted depend on the quantities of raw materials used as well as the nature and conversion efficiency of the manufacturing process.

Table 4.1 (shown previously in section 4.1.2) and Figure 4.20 present a comparison of CO_2 emission by different industries in 1990, 1995 and 1998. It is noticed that cement production was the largest contributor of CO_2 from industrial process, followed by food & beverage industries and lime manufacturing. Among the six main industries, iron & steel was the lowest emitter of CO_2.

In 1995, cement production emitted almost twice the amount of CO_2 compared to the year 1990. However, CO_2 emission decreased in 1998 because construction activity in Thailand decreased. The construction and cement data in Thailand is presented in Table 4.10.

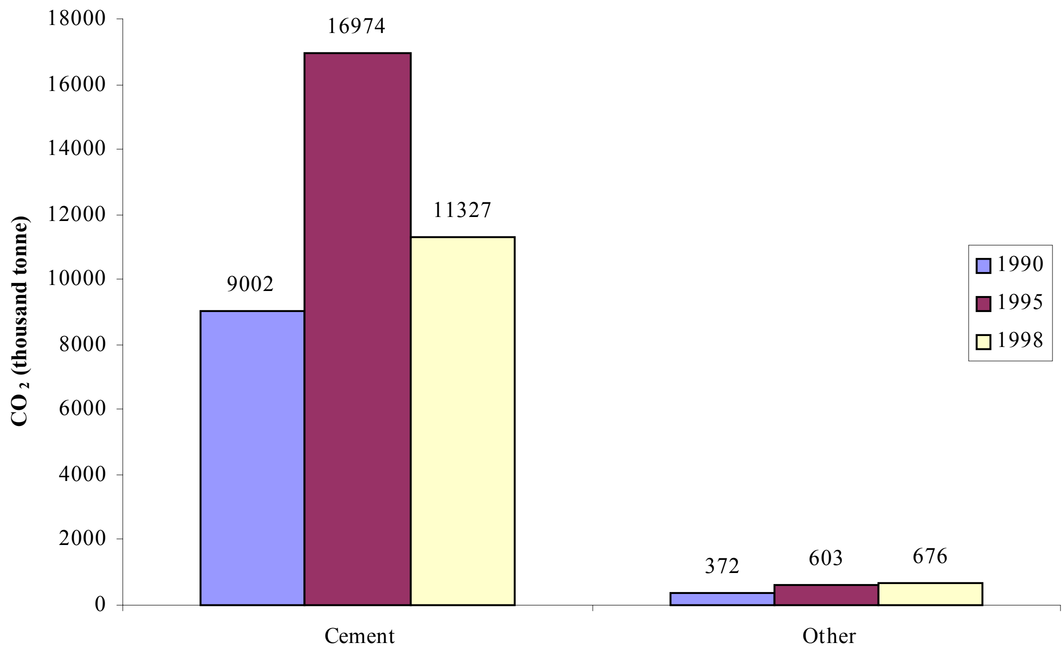


Figure 4.20 CO_2 emission (thousand tonne) by different industries in 1990, 1995 and 1998.

Table 4.10 Number of construction permit & cement production in Thailand.

Region	Year					
	1990		1995		1998	
	Construction (number)	Cement[1] (million tonne)	Construction (number)[2]	Cement[1] (million tonne)	Construction (number)[2]	Cement[1] (million tonne)
Bangkok	-[3]	-	30502	-	20789	-
Central	-	-	14674	-	12862	-
North	-	-	11656	-	8577	-
Northeast	-	-	15288	-	12438	-
South	-	-	10622	-	7061	-
Total	-	18	82742	34	61727	23

[1]Data from Bank of Thailand (2000)

[2]Data from National Statistic Office (1997, 1999)

[3]Not available

4.2.3 Agriculture.

Table 4.11 and Figure 4.21 present a comparison of CH_4 emission by different sub-sectors in 1990, 1995 and 1998. It is noticed that largest emitters of CH_4 was Rice Cultivation followed by Livestock. Among the three sub-sectors, Field Burning was the lowest emitter of CH_4.

In agriculture, despite stabilization in the total area used for rice cultivation, CH_4 emissions were increased from 2827 thousand tonne in 1995 to 3103 thousand tonne in 1998, due to an expansion in harvested area of paddy and more intensive fertilizer application. Different rates of expansion in the population of domestic animals were found in Livestock sub-sector, resulting a drop of CH_4 emission from livestock. The numbers of livestock data in Thailand are presented in Table 4.12.

Table 4.13 and Figure 4.22 present a comparison of N_2O emission by different sub-sectors in 1990, 1995 and 1998. It has been noticed that largest emitters of N_2O was Agriculture Soils sub-sector. Field Burning sub-sector was the lowest emitter of N_2O.

Table 4.11 CH_4 emission (thousand tonne) by different sub-sectors in 1990, 1995 and 1998.

Sub-sectors	CH_4 Emission		
	1990	1995	1998
Rice Cultivation	2847	2827	3103
Livestock	569	613	394
Field Burning	21	26	21
Total	590	639	415

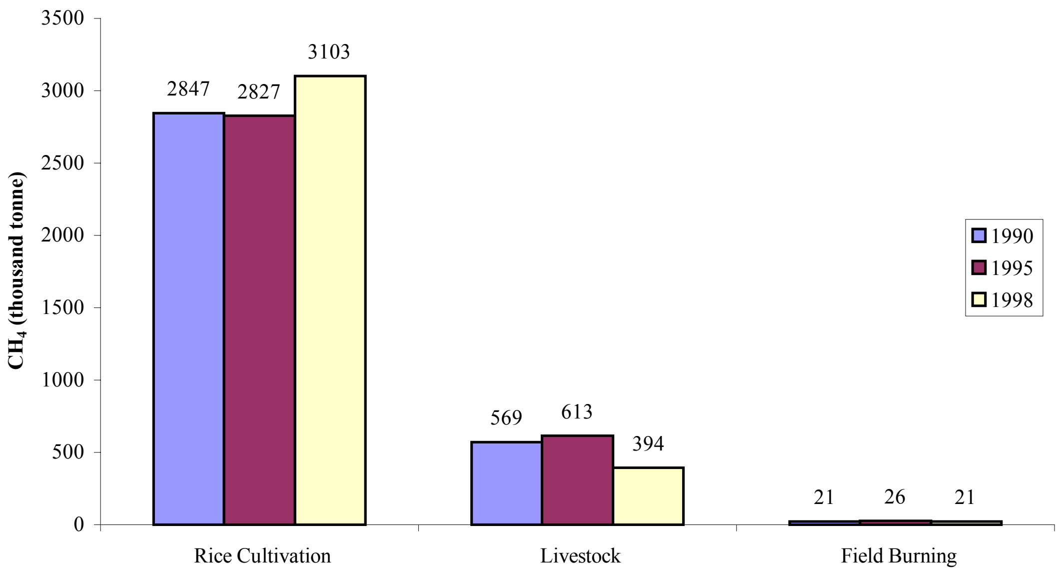


Figure 4.21 CH_4 emission (thousand tonne) by different sub-sectors in 1990, 1995 and 1998.

Table 4.12 Number of livestock in Thailand.

Type of animal	Year		
	1990	1995	1998
Dairy cattle	157537	287247	295345
Non-dairy cattle	5510993	7321821	4567950
Buffalo	4694290	3710061	1951068
Goat	120519	132400	130904
Sheep	162496	75329	40404
Swine	7349710	8561921	8772275
Horse	19758	16875	11322
Poultry	125979828	130958286	175280520

Source: Department of livestock Development (1993, 1996, 1998)

Table 4.13 N_2O emission (thousand tonne) by different sub-sectors in 1990, 1995 and 1998.

Sub-sectors	N_2O Emission		
	1990	1995	1998
Agriculture Soil	33.09	37.59	32.40
Field Burning	0.47	0.48	0.40
Total	33.56	38.07	32.80

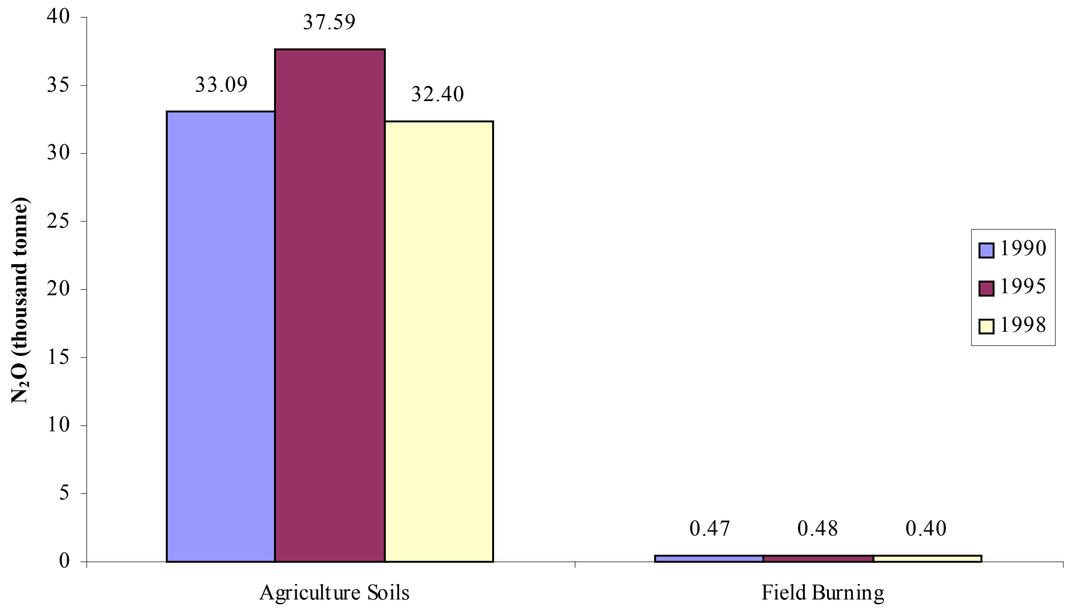


Figure 4.22 N_2O emission (thousand tonne) by different sub-sectors in 1990, 1995 and 1998.

In 1995, N_2O emission from agriculture soils increased because the fertilizer consumption and number of livestock increased. The fertilizer consumption and number of livestock data of Thailand are presented in Appendix E. But in 1998, N_2O emission from agriculture soils decreased because number of non-dairy cattle, buffalo, goat, sheep and horse in livestock sub-sector decreased in that year.

4.2.4 Forest

Table 4.14 and Figure 4.23 present comparison of net CO_2 emission from Thai forests by different activities in 1990, 1995 and 1998. CH_4 and N_2O were emitted from on-site burning by forest conversion activity (see Table 4.5). The results show that the greenhouse gas contribution from the Forestry sector decreased. Uncontrolled logging and deforestation from widespread conversion of forests into agriculture land and other uses have reduced significantly since the government passed legislation which declared a logging ban on 17 January 1989 (TEI, 1997). As a result, CO_2, CH_4, and N_2O emitted in 1990 was more than in 1995 and 1998.

Table 4.14 Net CO_2 emission (million tonne) by different activities in 1990, 1995 and 1998.

Activities	CO_2 Emission (a)			CO_2 Removal (b)			Net CO_2 Emission (a-b)		
	1990	1995	1998	1990	1995	1998	1990	1995	1998
Change in Forest	29	30	31	0.9	0.6	0.2	28	29	30
Forest Conversion	87	34	18				87	34	18
Abandonment of Managed Land				25.4	24.2	22.4	-25	-24	-22
Total	116	64	49	26.3	24.8	22.6	90	39	26

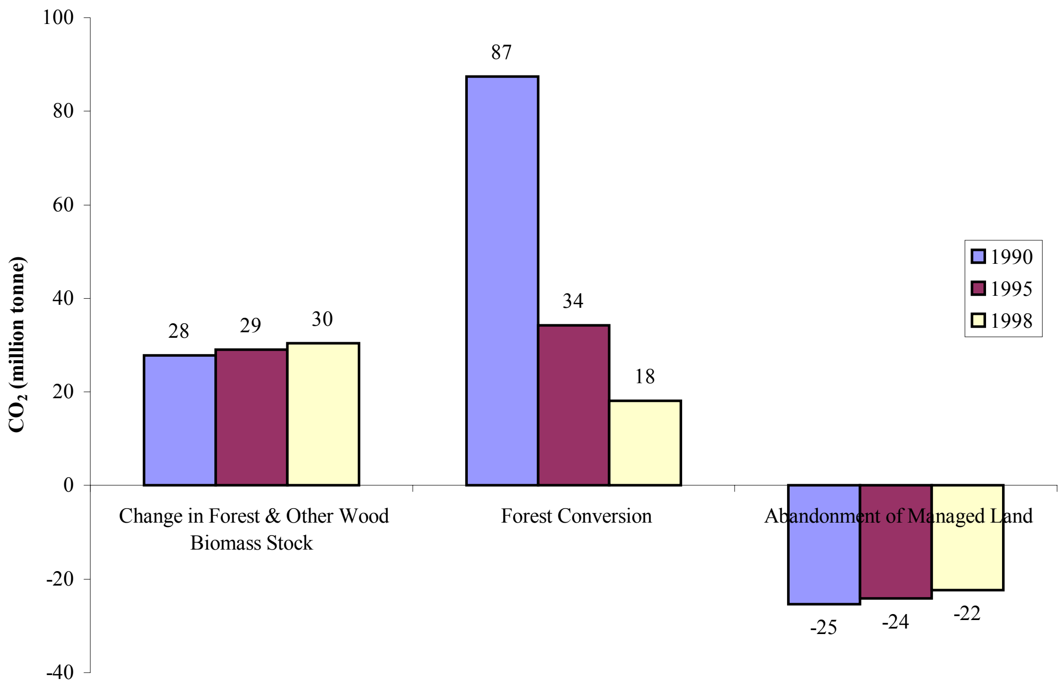


Figure 4.23 CO_2 emission (million tonne) by different activities in 1990, 1995 and 1998.

4.2.5 Waste

Table 4.15 and Figure 4.24 present the emission of CH_4 by different sub-sectors in 1990, 1995 and 1998. CH_4 emitted from Waste sector has increased through the three years. Increasing population and the growing volume of solid waste coupled with gradual phase-out of open dumping facilities in favor of sanitary landfill, resulted in moderate increase of greenhouse gas emissions from solid wastes and domestic wastewater. However, estimation of greenhouse gas emissions from industrial wastewater has uncertainties regarding data about investments in anaerobic treatment facilities and wastewater characteristics of the industry as well as the location, types, technologies and processes involved. The waste data describing quantities of waste in land fill and open dumping disposal sites, waster used and number of factories in Thailand are presented in Appendix E.

4.2.6 Net Emission of CO_2 Equivalent Greenhouse Gases

Figure 4.25 present the net emission of CO_2 equivalent by different sectors. It is noticed that the largest emitters of greenhouse gas was Energy sector followed by Agriculture, and Forest sectors. Among the five sectors, Industrial Processes and Waste sectors were the lowest emitters of greenhouse gases in the three years.

Contribution of the three most important greenhouse gases are examined for the three major high GHGs emission sectors in Thailand: Energy, Agriculture, and Forest. From Figure 4.26, it can be noticed that CO_2 constitutes more than 95% of the total CO_2 equivalent greenhouse gases emitted by Energy and Forest sectors. Agriculture sector was identified as a major source of atmospheric CH_4 and N_2O. CH_4 emission is more than 86% of the total CO_2 equivalent greenhouse gas emissions from this sector.

Table 4.15 CH_4 emission (thousand tonne) by different sub-sectors in 1990,1995 and 1998.

Sub-sectors	CH_4 Emission		
	1990	1995	1998
Solid Waste Disposal on Land	131	208	284
Wastewater Treatment	296	392	424
Total	427	600	709

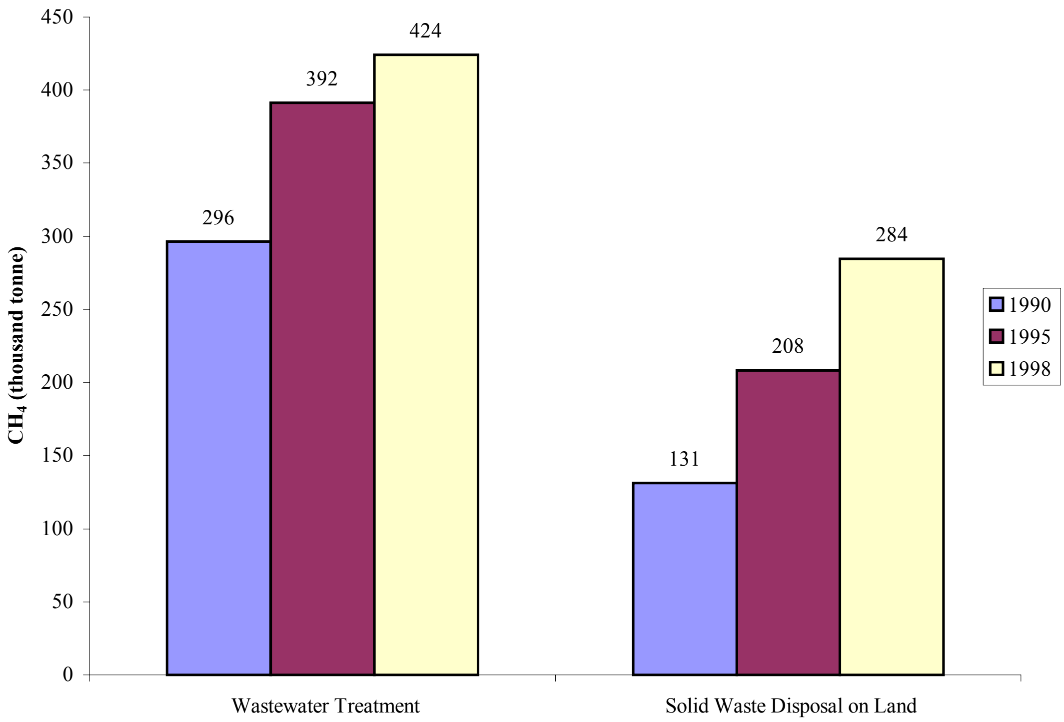


Figure 4.24 CH_4 emission (thousand tonne) by different sub-sectors in 1990, 1995 and 1998.

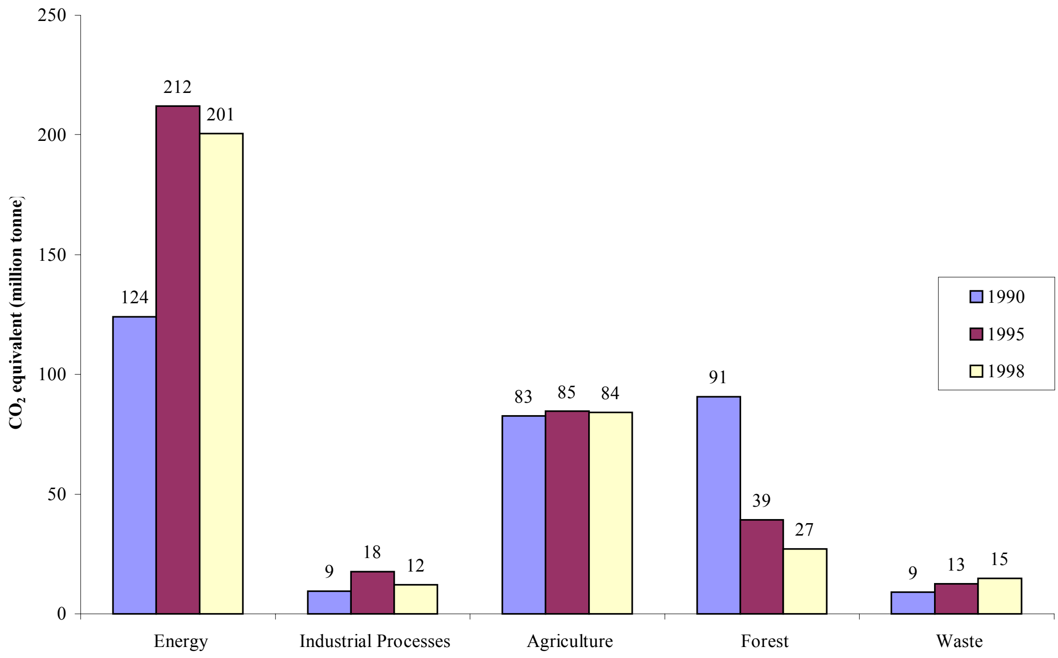


Figure 4.25 CO_2, CH_4 and N_2O emission in CO_2 equivalent (million tonne) by different by sectors in 1990, 1995 and 1998.

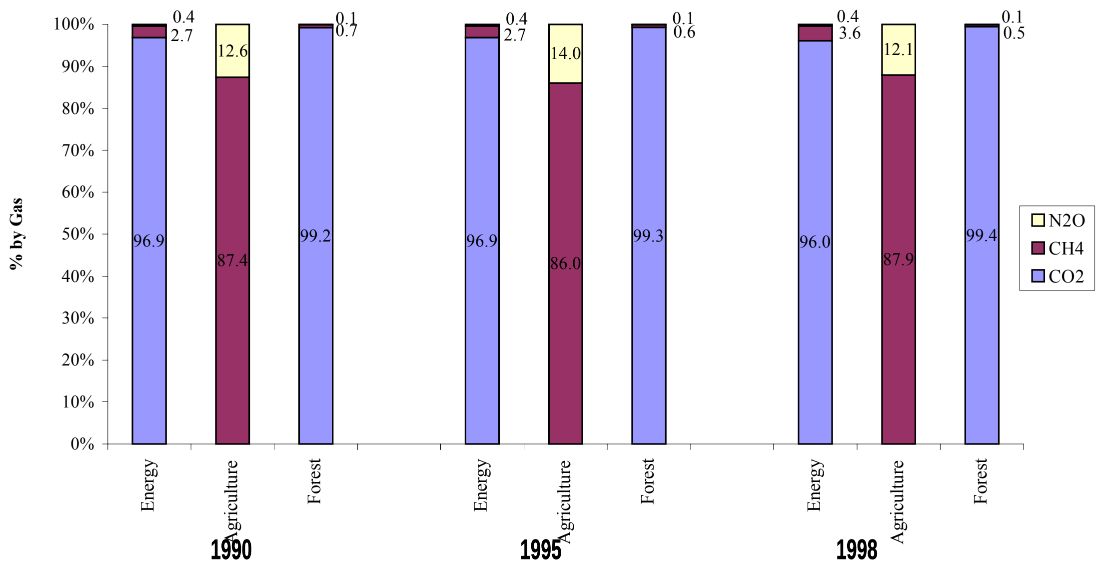


Figure 4.26 Percent by gas of total CO_2 equivalent from different sectors in 1990, 1995 and 1998.

4.3 Greenhouse Gases Emission Comparison among the Selected Countries

The Asia-Pacific Region is one of the world's most significant for studying climate change and potential strategies to address it. Countries in the region have major portions of the world's remaining natural tropical forests, plus the majority of the world's population. The Region's forests are not only extensive terrestrial sinks of greenhouse gas, but also major reservoirs of global biological diversity. Developed countries have been responsible for most CO_2 emissions and, therefore, bear much of the responsibility for the problems associated with climate change. However, the Asia-Pacific Region is projected to become one of the world's largest contributors of greenhouse gas emission.

In this section, a comparison of greenhouse gas emissions between Thailand in the year 1990 and 1995 and other countries is done. Selected countries include those in Asia-Pacific Region (China, India, Indonesia, South Korea, Philippine, and Vietnam) using the data in year 1990 (as the data for 1995 is not available) and those in other continents (United States, Germany, Australia, and Japan) using the data in the year 1990 and 1995, taken from the data of UNFCCC (2001).

Figure 4.27 and Figure 4.28 present population and greenhouse gas emission by CO_2 equivalent in different countries, respectively. China is the world's most populous country and the second largest emitter of greenhouse gas after than United States. Among the eleven countries, Thailand stands for the fifth place from the bottom in the rank of total greenhouse gas emissions while Vietnam is in the lowest place.

Contribution of the major greenhouse gases are examined as shown in Figure 4.29. CO_2 constitutes more than 72% of the total CO_2 equivalent greenhouse gases emitted in developed countries and 50% in developing countries. Public concern about global warming mostly focuses on CO_2, the most prevalent greenhouse gas. Methane (CH_4), the major component of natural gas, is second important as a greenhouse gas. Rice cultivation is a major source of atmospheric methane. CH_4 emission of Vietnam, India, Indonesia and Thailand is equal to 49%, 39%, 32%, and 25% of the total CO_2 equivalent greenhouse gas emissions of each country, respectively.

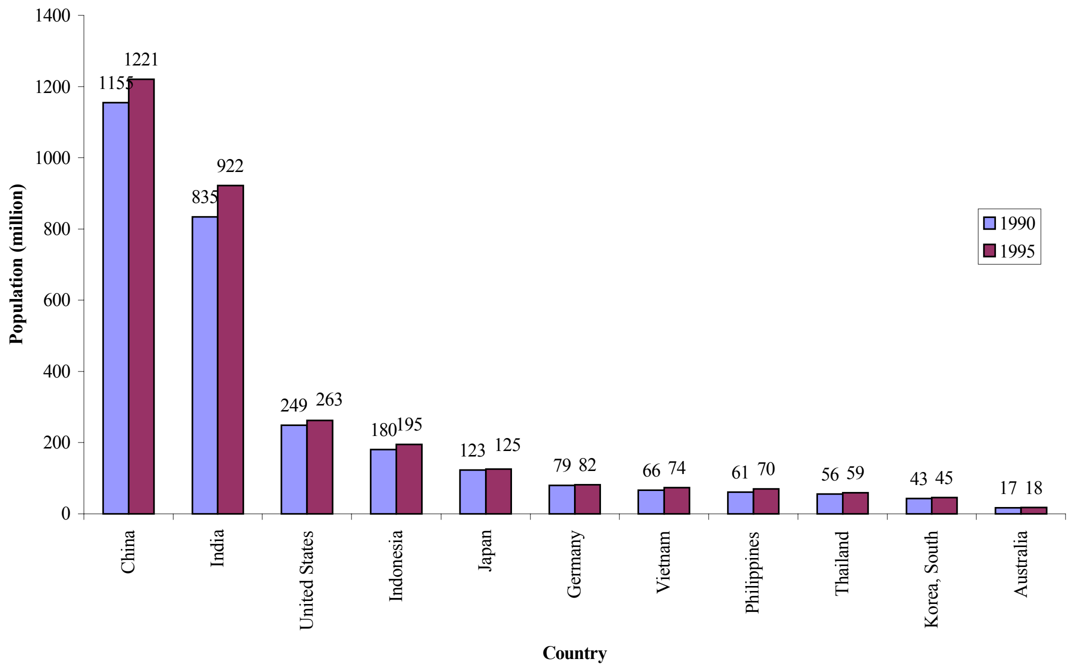


Figure 4.27 Comparison of population (million) among the selected countries in 1990 and 1995.

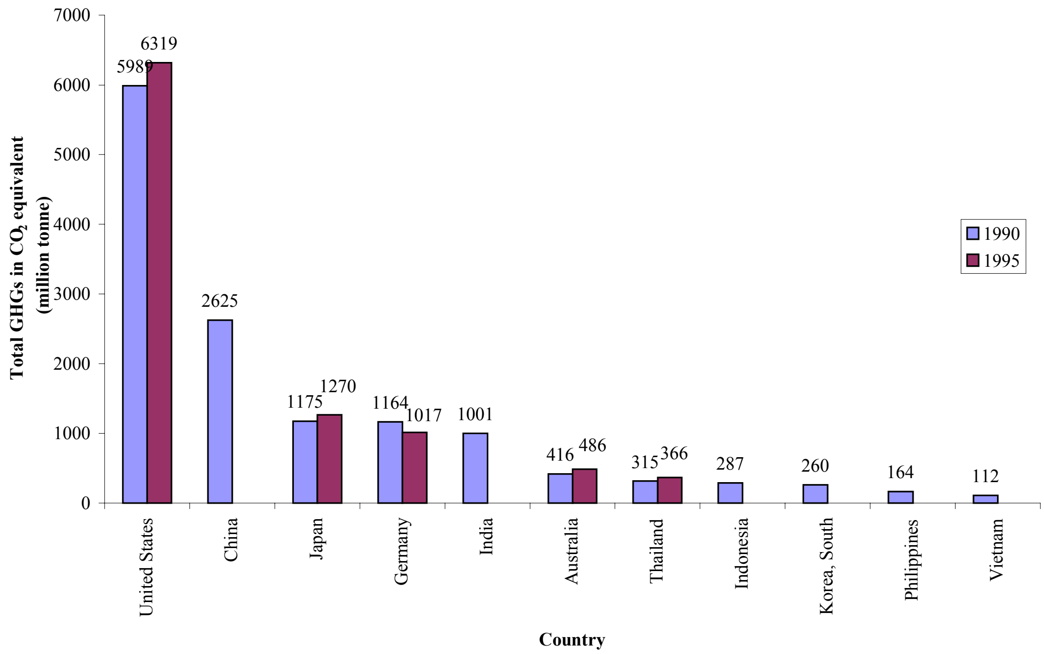


Figure 4.28 Comparison of total greenhouse gases emission in CO_2 equivalent (million tonne) among the selected countries in 1990 and 1995.

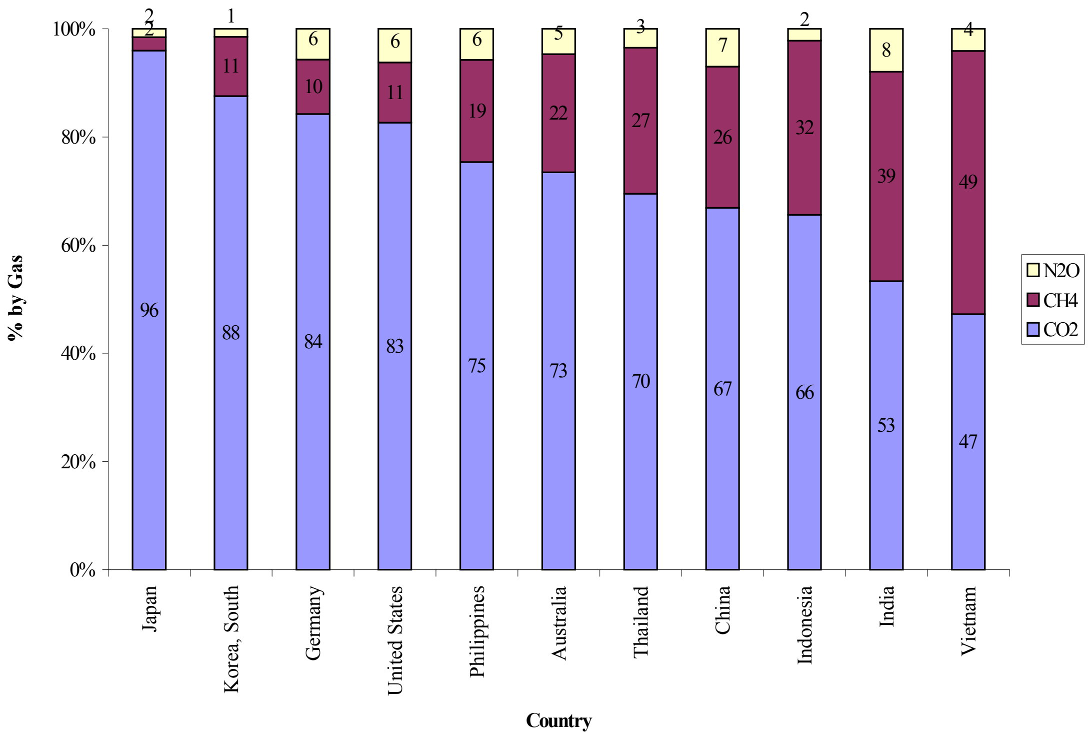


Figure 4.29 Total CO_2 equivalent from selected countries in percent by gas in 1990.

Since more than 50% of greenhouse gas emissions that were emitted from each country are CO_2, CO_2 emissions were used for further comparison among selected countries

Figure 4.30 shows the total CO_2 emissions of the eleven countries. The total CO_2 emission in each country has nearly the same patterns of the total greenhouse gas emissions as CO_2 equivalent (see Figure 4.28). Thailand is in the middle for the overall total CO_2 emission rank. Here, United States obtains the highest value while Vietnam has the lowest one.

Thailand and some countries in Asia-Pacific Region are developing countries. Because of its growing population and rapid economic development, the amount of CO_2 emissions is expected to increase in the near future. However, from the Figure 4.31, the per capita emission level is still much lower than developed countries. Among the eleven countries, Thailand stands at the fifth place from the bottom in rank of per capita emission while China has the lowest value. Japan, United States, Germany and Australia have extremely high values of emission per capita. Thus, from

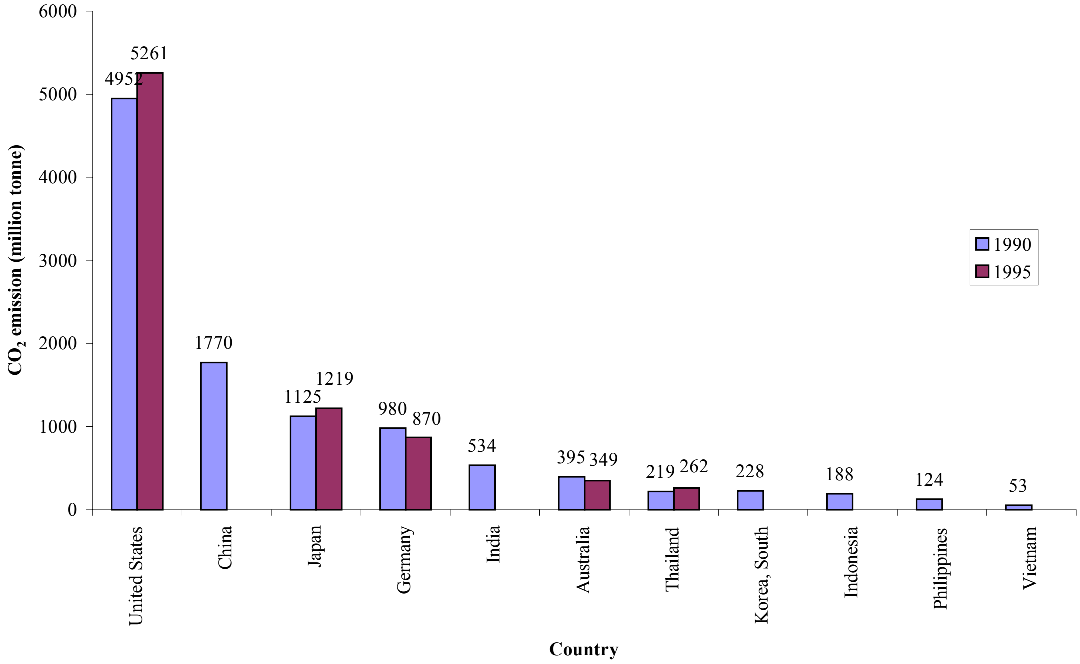


Figure 4.30 Comparison of CO_2 emission (million tonne) among the selected countries in 1990 and 1995.

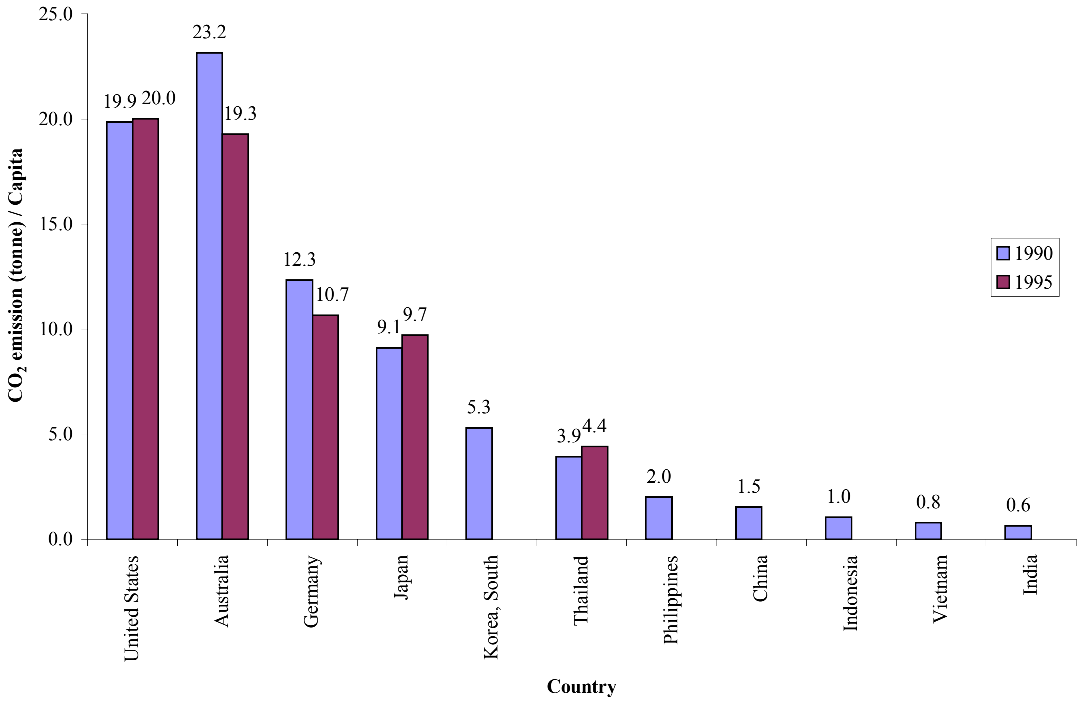


Figure 4.31 Comparison of CO_2 emission (tonne) per capita among the selected countries in 1990 and 1998.

the two Figures, it can be concluded that developed countries have both CO_2 emission and CO_2 emission per capita higher than developing countries.

Population and economic growth, structural change in economies, energy prices, technological advance, fossil fuel supplies, nuclear and renewable energy availability are among the factors which could exert major influence on future level of CO_2 emissions. Paul Ehrlich and John Holdren (1974) have examined the relationship between the environmental impacts and three factors. Their equation is sometimes called the "IPAT" model:

$$I = P \times A \times T$$

where I is the environmental impact

P is population size

A is per capita economic activity (referred to as affluence)

T is the impact per unit economic activity (referred to as technology).

When applied to global warming, I represents total CO_2 emissions, A stands for GDP per capita and T stands for the amount of CO_2 emitted per GDP.

Figure 4.32 presents GDP per capita in different countries, i.e. the affluence. It is noticed that the affluences differed largely when compared between developed countries and developing countries. Developed countries have the highest value with extremely high affluence. Figure 4.33 presents the emission of CO_2 per GDP, i.e. the technology. It is noticed that developed countries have the emission of CO_2 per GDP lower than developing countries. The technology in use to generate products in developed countries is of higher efficiency than that is in use in developing countries. Generally, developed countries have better or cleaner technology. From the IPAT model, however, they have more impact to the environment because of their higher affluence, i.e. the GDP/capita. In addition, population size is one factor that should not be neglected. Although China has the lowest affluence, it is the world's most populous country and the second largest emitter of CO_2. It is also apparent that development of technology in Asia-Pacific Region such as Thailand, China, India and others is of great importance in view of the reduction of GHGs emission.

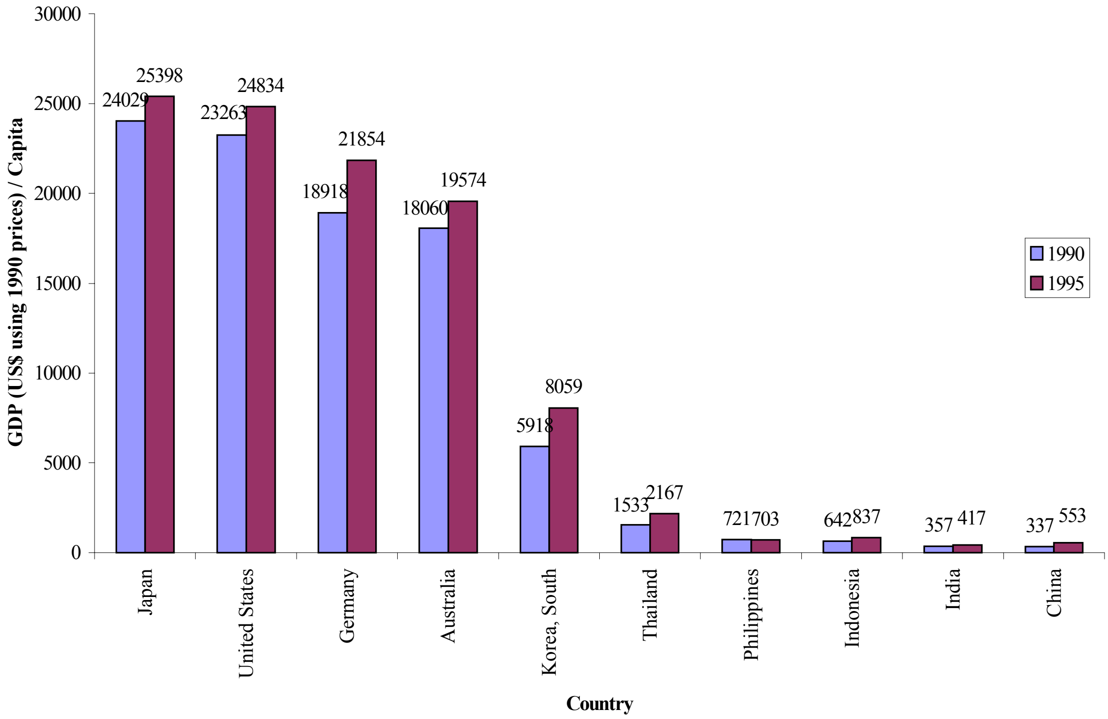


Figure 4.32 Comparison of US$ GDP per capita among the selected countries in 1990 and 1995 (International Energy Agency, http://www.eia.doc.gov).

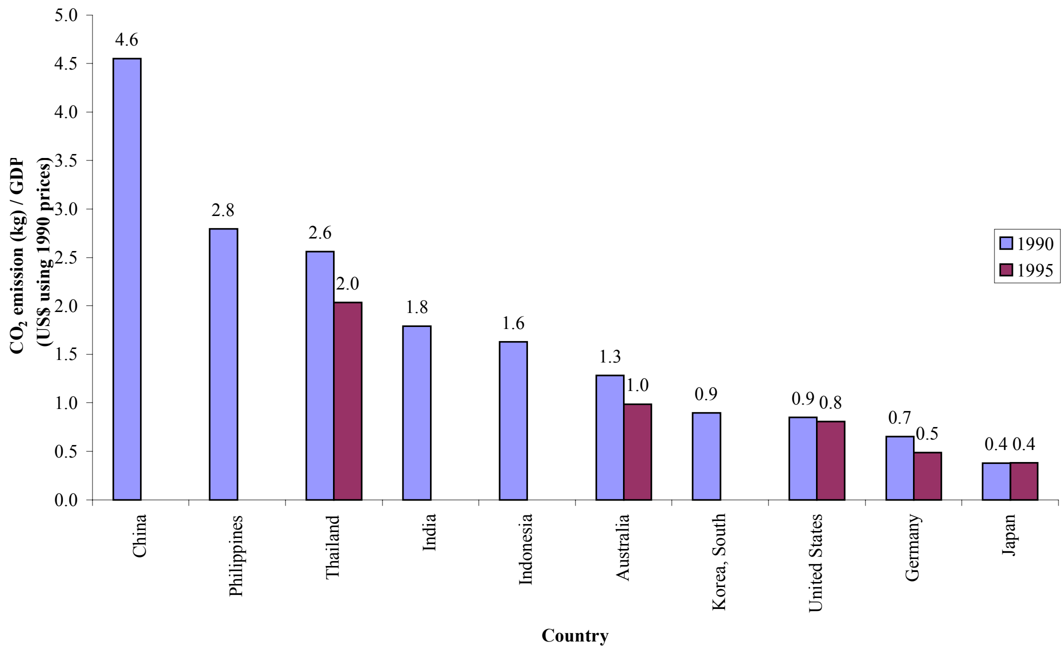


Figure 4.33 Comparison of CO_2 emission (kg) per US$ GDP among the selected countries in 1990 and 1995.

4.4 Improvement and Refinement of IPCC Methodology

The estimation of greenhouse gases relies on the quality of data used. This study faced problems of selecting the proper data from many possible sources, in order to obtain the most accurate estimation for Thailand. The methodology used mostly for the greenhouse gases estimation is the IPCC methodology (IPCC, 1996). It requires the Emission Factor (EF) Values for the calculation of every sector. The proper values of EF for each sectors may be different for different countries due to the difference in weather, geographical characteristics, production (i.e. agriculture or industry), technology, and other characteristics. The follows are the improvement and refinement of the IPCC methodology done in this study.

For the Industrial Processes sector, the EF values used were obtained from Kessmanee (1997) because they are more specific to Thai industrial processes than the IPCC' s default values. For the Rice Cultivation sector, the IPCC default values are derived from values of various countries and therefore have a wide range and large uncertainty. To reduce the uncertainty, this study used the EF value from a study of Smakgahn et al, which is more recent and focuses more on local EF value for different rice cultivation processes in Thailand (Smakgahn et al, 2000). The comparison between the rice cultivation EF values from IPCC and Smakgahn et al is shown in Table 4.16.

Table 4.16 CH_4 emission factor (kg-CH_4/ha-day) for Rice Cultivation sector.

Cropping Season	Water Regimes	Emission Factor (kg CH_4/ha-day)	
		IPCC	This Study
Major Rice (Wet season)	Irrigated	6.25	2.234
	Rainfed	3.75	2.998
	Deep Water	6.25	0.817
Second Rice (Dry season)	Irrigated	6.25	2.234

The improvement in the Agriculture Soils sector concerns the calculation of the nitrogen in crop residues returned to soil (F_{CR}) for each crop, which is presented in Appendix D. The first improvement is the use of plant-specific nitrogen content values of Thailand instead of the IPCC's one default value for all non-N-fixing crop ($Frac_{NCRO}$) and one for all N-fixing crop ($Frac_{NCRBF}$). The second improvement is the calculation method for the F_{CR}. Instead of estimating indirectly the amount of crop residues based on the crop yield, this study used the crop residues values directly. The Thai crop residue values in the unit of tonne per hectare were multiplied by the harvested area to give the total crop residues. The example for comparison between IPCC and improved methodology are showed below.

Example: This example shows the calculation of the F_{CR} of soybean in year 1995, by using the IPCC methodology and methodology used in this study. The fraction of crop residues that was burned ($Frac_{BURN}$) and removed form the fields as crop ($Frac_R$) are assumed at 0.25 and 0.45 kg N per kg crop-N, respectively. The IPCC's default value of the fraction of nitrogen in N-fixing crops ($Frac_{NCRBF}$) was 0.03 kg-N/kg-dry biomass. Soybean yield was 385560 tonne/yr. Crop residues per planted area was 3.125 tonne/ha. The specific nitrogen content value for soybean was 0.0136 kg-N/kg-dry biomass. The harvested area was 275040 ha.

Calculation:

IPCC:

$$F_{CR} = 2 \times [\text{Crop Yield}_{(\text{N-fixing crop})} \times Frac_{NCRBF} + \text{Crop Yield}_{(\text{non-N-fixing crop})} \times Frac_{NCRO}] \times (1 - Frac_R) \times (1 - Frac_{BURN})$$

$$F_{CR} = 2 \times [385560 \text{ tonne/yr} \times 0.03 \text{ kg-N/kg-dry biomass} + 0] \times (1 - 0.45) \times (1 - 0.25)$$

$$= 3180.87 \text{ tonne/yr}$$

This study:

$$F_{CR} = \text{Harvested area} \times \text{Crop residues} \times \text{N content} \times (1 - Frac_R) \times (1 - Frac_{BURN})$$

$$F_{CR} = 275040 \text{ ha} \times 3.125 \text{ tonne/ha} \times 0.0136 \text{ kg-N/kg-dry biomass} \times (1 - 0.45) \times (1 - 0.25) = 4821.79 \text{ tonne/yr}$$

Thailand is an agricultural country. Therefore, the estimation of greenhouse gases value of the Agriculture sector is important. The new method used in this study help reducing the possible error in estimation.

In this study, the using of IPAT model (section 4.3), it was found that developed countries have both CO_2 emission and CO_2 emission per capita higher than that of developing countries. Generally, developed countries have better or cleaner & productive technology. However, they have more impact on the environment because of their higher affluence, i.e. the GDP/capita. Although China has the lowest affluence, it is the world's most populous country and the second largest emitter of CO_2. The population size is one factor that should not be neglected when developing the methodology for the proper estimation of greenhouse gases in Thailand. According to BAI Naibin (2000), many authors indicated that the respiration is one of the major natural sources for CO_2 emission. The study implies population number of China for the estimation of CO_2 emission from respiration and uses the following equation:

$$CO_2 \text{ emission} = \text{Number of population} \times 0.0789 \text{ tonne C/person/yr}$$

Using the equation for the estimation of CO_2 emission for Thailand, which has 59,460,382 persons in year 1995, the following result has been obtained:

CO_2 emission = 59460382 person × 0.0789 tonne C/person/yr

= 4691424 tonne C/yr ×(44/12) CO_2/C

= 17×10^6 tonne CO_2/yr

= 17×10^3 Gg CO_2/yr

In this case, CO_2 emission from population respiration is 6.5% of total CO_2 emission estimated originally in this study. It almost equals CO_2 emission from Industrial Processes sector (6.7%).

CHAPTER V
CONCLUSIONS AND RECOMMANDATIONS

5.1 Conclusions

Global warming, the result of excess emission of the so-called "greenhouse gases" that give rise to the greenhouse effect, has presently become a major threat confronting the people and the governments of the world at large. The major players in causing this greenhouse effect have been identified as the gases like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

This study has estimated the emission of the greenhouse gases in Thailand for the years 1990, 1995 and 1998 from various sources including energy use, industrial processes, livestock, rice cultivation, field burning of agriculture residue, agriculture soils, forestry and waste sectors; and discussed the environmental implications of these gases in the context of Thailand. In order to make the estimation, this study mainly followed the Intergovernmental Panel for Climate Change (IPCC) methodology (1996) and other relevant and latest information available for Thailand and other developing countries. This study also addressed the importance of improvement and refinement of the current IPCC methodology for appropriate usage in Thailand.

The major sectors responsible for emission of the greenhouse gases in Thailand are Energy, Agriculture, and Forest sectors. CO_2 constitutes more than 95% of the total CO_2 equivalent greenhouse gases emitted in Energy and Forest sectors. Agriculture sector is identified as a major source of atmospheric methane and nitrous oxide. CH_4 emission in Agriculture sector is more than 86% of the total CO_2 equivalent greenhouse gas emissions from this sector.

In 1995, Energy and Industrial Processes sectors emitted almost twice the amount of CO_2 equivalent compared to year 1990. However, CO_2 equivalent emission decreased in 1998 because the economic crisis in 1997 that was continued to 1998.

Agriculture sector emitted almost same amounts of CO_2 equivalent in all the three years. Forest sector emitted the amount of net CO_2 which decreased continuously. The net CO_2 equivalent emissions from Forest sector in 1990 and 1995 changed considerably because the government passed a legislation which declared a logging ban effective from January of 1989.

In terms of the national inventory, the Energy sector is the dominant sector in its share and rate of growth of greenhouse gases emissions. The Wastes sector also shows rapid increase in greenhouse gases emissions. This suggests that the Energy sector and the Waste sector need to be a primary focus for the mitigation of greenhouse gases emissions. This study provides, in Appendix F, a list of mitigation options for greenhouse gases emissions in Thailand from four sectors: Energy, Agriculture, Forest, and Waste.

From emission comparison among selected countries, it was found that CO_2 constitutes more than 72% of the total CO_2 equivalent greenhouse gases emitted in developed countries and 50% in developing countries. Thailand is in the middle for the overall total CO_2 emission rank. United Stated has the highest value, while Vietnam has the lowest one. The CO_2 per capita emission level is still much lower than that of developed countries. Among the eleven countries, Thailand stands at the fifth place from the bottom in rank of per capita emission while China has the lowest value. Japan, United States, Germany and Australia have extremely high values of emission per capita. It can be concluded that developed countries have both CO_2 emission and CO_2 emission per capita higher than developing countries.

GDP per capita in different countries, i.e. the affluence, differed largely when compared between developed countries and developing countries. Developed countries have the highest value with extremely high affluence. Comparison on the emission of CO_2 per GDP, i.e. the technology, showed that developed countries have lower values than developed countries. The technology being used to generate product of developed countries is of higher efficiency than developing countries.

Emission factors vary from country to country due to the difference in weather, geography, technology, and other factors. In this study, the emission factors of Industrial Processes and Rice Cultivation sectors were selected from the literature that are the most appropriate for Thailand. Another improvement was for Agriculture

Soils sector, in the calculation of net N entirely soil (F_{CR}) for each crop type. The importance of population number and CO_2 emission from respiration was also considered.

5.2 Recommendations for Future Studies

Some activities that should be done in the future include:

1. Further development of a national database of research information related to the greenhouse gases emissions and uptake data. This database is needed to develop assumptions used for the improvement of future estimation greenhouse gases emissions and also for verifying and improving greenhouse gases sources and sinks coefficients.

2. Research and development of the emission factor values for each sector (such as Energy, Agriculture, Land Use Change & Forestry, and Wastes) for the proper estimation of greenhouse gases in Thailand.

3. Development of a more accurate method for the measurement and estimation of greenhouse gases from Agriculture sector in the country , which is essential for an agricultural country like Thailand.

4. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) are used as alternative to ozone depleting substances being phased out under the Montreal Protocol. Many of these compounds have high global warming potentials (GWPs) and long atmospheric lifetimes. Then, these are interesting gases for studying in the future.

5. Because of the population respiration is one of the major natural sources for CO_2 emission. The method that account for greenhouse gases emission of population respiration should be developed.

References

Aksornkaew, S. (1989). **Mangroves ecology and management.** Kasetsart University. Bangkok. Thailand.

Aksornkaew, S., J. Kongsangchai and V. Jintana. (1987). Ecological equilibrium and productivity of mangrove forest in Thailand. **Thai J. Forest.** 6: 160.

Asian Development Bank (ADB). (1998a). **Asia least-cost greenhouse gas abatement strategy (ALGAS): China.** ADB.

Asian Development Bank (ADB). (1998b). **Asia least-cost greenhouse gas abatement strategy (ALGAS): India.** ADB.

Asian Development Bank (ADB). (1998c). **Asia least-cost greenhouse gas abatement strategy (ALGAS): Indonesia.** ADB.

Asian Development Bank (ADB). (1998d). **Asia least-cost greenhouse gas abatement strategy (ALGAS): Philippine.** ADB.

Asian Development Bank (ADB). (1998e). **Asia least-cost greenhouse gas abatement strategy (ALGAS): Republic of Korea.** ADB.

Asian Development Bank (ADB). (1998f). **Asia least-cost greenhouse gas abatement strategy (ALGAS): Thailand.** ADB.

Asian Development Bank (ADB). (1998g). **Asia least-cost greenhouse gas abatement strategy (ALGAS): Vietnam.** ADB.

BAI Naibin. (2000). Estimation of emissions of greenhouse gases and their in creases in China, 1949-1997. In **The first regional conference on energy technology towards a clean environment** (pp 340-360). Bangkok: NSTDA.

Bank of Thailand. Industrial Section Department of Economic Research. (2000). **Raw Data.**

British Columbia Ministry of Environment, Land & Parks. (2000). **Global climate change** [On-line]. Available: http://www.elp.gov.bc.ca/epd/pdpa/ar/climate/gccauu.html.

CMS Environment Consultant. (1997). **The project assessment of the waste water solution from Industrial sector in Thailand.** Bangkok.

Department of Energy Development and Promotion. (1991). **Thailand energy situation 1991.** Bangkok: T.P. Print.

Department of Energy Development and Promotion. (1999). **Thailand energy situation 1999.** Bangkok: T.P. Print.

Department of Livestock Development. (1993). **Yearly statistics report 1993.** Bangkok. Thailand.

Department of Livestock Development. (1996). **Yearly statistics report 1996.** Bangkok. Thailand.

Department of Livestock Development. (1999). **Yearly statistics report 1999.** Bangkok. Thailand.

EGAT. (1999). **Annual report: 1998.** EGAT. Thailand.

Industrial Works Department. Factories Database form Statistic Division. (1999). **Raw data.**

Intergovernmental Panel on Climate Change. (1990). **Climate change: The IPCC scientific assessment**. IPCC. Quoted in The petroleum authority of Thailand. (2000). Eccentric global, temperature dry land and melting ice. **Power the Thought** 8 (2) 41-43.

Intergovernmental Panel on Climate Change. (1994). **The 1994 report of the scientific assessment working group of IPCC**. IPCC. Quoted in British Columbia Ministry of Environment, Land & Parks. (2000). **Global climate change** [On-line]. Available: http://www.elp.gov.bc.ca/epd/pdpa/ar/climate/gccasu.html

Intergovernmental Panel on Climate Change. (1996a). **Revised 1996 IPCC: Guideline for national greenhouse gas inventories, Vol. II: Greenhouse gas inventory workbook**. IPCC.

Intergovernmental Panel on Climate Change. (1996b). **Revised 1996 IPCC Guideline for national greenhouse gas inventories, Vol. III: Greenhouse gas inventory reference manual**. IPCC.

Intergovernmental Panel on Climate Change. (2000). **Good practice guidance and uncertainty management in national greenhouse gas inventories**. IPCC.

International Energy Agency. (2000a). **Energy** [On-line], Available: http://www 1.klc.lu.se/iiee/sources/energy/energy_home.html

International Energy Agency. (2000b). **Table economics** [On-line]. Available: http://www.eia.doc.gov/emeu/iea

Jermsawatdipong, P. (1997). Greenhouse gas mitigation option in agriculture sector. In.**Greenhouse gas mitigation option**. TEI. Bangkok. Thailand.

Kakwani, N. (1999). Impact of economic crisis on the standard of living in Thailand. **Newsletter of NESDB.** 3(1). Bangkok. Thailand.

Kessmanee, C. (1997). **A study of greenhouse gas emission from the industrial process**. M.S. thesis, King Mongkut's University of Technology Thonburi.

King Mongkut Institute of Technology Thonburi (KMITT). (1995). **Recycling of organic matter and reduction of CO_2 emission of cane trash.** KMITT. Bangkok. Thailand.

Korakotjintanakarn, P. (1998). **CO_2 emission from power generating sector and important related issue**. M.E. thesis, King Mongkut's University of Technology Thonburi.

Lawrence Berkeley Laboratory (LBL). (1995). **Guidance for mitigation assessments version 2.** Lawrence Berkeley Laboratory. Berkeley. California. USA.

Metropolitan Waterworks Authority. (2000). **Statistical data fiscal year 2000.** Metropolitan Waterworks Authority. Bangkok. Thailand.

National Economical and Social Development Board (ENSDB). (2000). **Input-output table of Thailand 2000**. Bangkok: ENSDB.

National Statistics Office. (1997). **Construction statistics year 1995.** Bangkok. Thailand.

National Statistics Office. (1999). **Construction statistics year 1998.** Bangkok. Thailand.

National Statistical Office. (2000). **Statistical yearbook Thailand.** National Statistical Office. Bangkok. Thailand.

Natural Resource Management Program (NRM). (1998). **A study and data base construction for anthropogenic greenhouse gases in Thailand.** TEI. Bangkok. Thailand.

Office of Agriculture Economic (1999). **Annual report on rainy season rice crop year 1997/1998.** Bangkok. Thailand.

Office of Agriculture Economic. (2000a). **Agricultural statistics of Thailand crop year 1998/1999.** Bangkok. Thailand.

Office of Agricultural Economic. (2000b). **Chemical fertilizer situation.** Bangkok. Thailand.

Office of Environment at Policy and Planning (OEPP). (2000). **Thailand environment situation year 1999**. OEPP. Bangkok. Thailand.

Ogawa, H., K. Ogino and T. Kira. (1965). Comparative ecological studies on three mains types of forest vegetation in Thailand. **Nature and Live in South East Asia.** 4: 49.

Paul Ehrlich and John Holdren. (1974). **Population and Environment Relationships.** University of North Carolina.

Pintukanok, A., M. Fukami and H. Wada. (1988). Organic waste material in Thailand. In **The sustained soil fertility in tropic regions as affected by organic waste materials.** Kasetsart University. Bangkok. Thailand.

Piriyapan. V. (1982). Agricultural Residue Utilization. In **The nation workshop on agricultural and agro-industrial residue utilization.** Phetchaburi. Thailand.

Pongprayoon, P. (1998). **Study of greenhouse gas resulting from land use change and forestry sector in Thailand**. M.S. thesis, King Mongkut's University of Technology Thonburi.

Provincial Waterworks Authority. (1998). **Annual report 1998.** Provincial Waterworks Authority. Bangkok. Thailand.

Royal Forest Department. (1993). **Thai forest sector master plan: Subsectoral plan for production and utilization.** Royal Forest Department**.** Bangkok. Thailand.

Royal Forest Department. (1999). **Forestry statistics of Thailand.** Data Center. Information Office. Bangkok. Thailand.

Samkgahn, K., Towprayoon, S. and Gale, G.A. (2000). Application of country scaling factor to estimate methane emission from rice fields. In **The first regional conference on energy technology towards a clean environment** (pp 381-387). Bangkok: NSTDA.

Sangtongpraw, S. and S. Sukwang. (1981). Economic assessment of forest resources in the SERS, Amphoe Pakthongchai, Nakhon Ratchasima Province. **Dep. Forest Biol. Fac. of For. Kasetsart University Technical Paper. No. 13.** Bangkok. Thailand.

Sahunalu P. and M. Jamreonpruksa. (1980). **Production and nutrient circulation of dry dipterocarp forests in Thailand.** Faculty of Forestry. Kasetsart University. Bangkok. Thailand.

Sahunalu P., P. Dhamanonda, w. Suwannapinunt, S. Kaitpraneet and P. Sri-Aran. (1981). Primary production of pine plantations. **Forest Research Bulletin No. 77.** Faculty of Forestry. Kasetsart University. Bangkok. Thailand.

Sathaye, J. A., W.R. Makundi and K. Andrasko. (1994). **A Comprehensive mitigation assessment process (COMAP) for evaluating response option in forest.** (paper submitted to biomass and bioenergy, July 1994).

Sirirutpiriya, O. (1997). **Impact of global change from greenhouse gases on rice cultivation**. The Institute of Environmental Research, Chulalongkorn University. Bangkok: University of Chulalongkorn Press.

Tanyadee, P. (1986). **The study and analysis of the compost industry status in Thailand.** Soil and Water Conservation's Division. Land Development Department. Bangkok. Thailand.

Thailand Development Research Institute (TDRI) and Thailand Environment Institute (TEI). (1993). **Preparation of a national strategy on global climate.** Bangkok. Thailand. (Report submitted to the government of Thailand).

Thailand Environment Institute. (1993). Greenhouse warming and Thai-where do we stand today. **TEI Quarterly Environment Journal** 1 (October-December): 5-10. Quoted in Orawan Sirirutpiriya. (1997). **Impact of global change from greenhouse gases on rice cultivation**. The Institute of Environmental Research, Chulalongkorn University. Thailand.

Thailand Environment Institute. (1997). **Thailand's national greenhouse gas inventory, 1990**. Bangkok: TEI.

The Petroleum Authority of Thailand. (2000). Eccentric global temperature, dry land and melting ice. **Power the Thought** 8 (2): 41-43.

The United Nations Framework Convention on Climate Change (UNFCCC). (2000). **Greenhouse gases emission** [On-line]. Available:http://www.UNFCCC.

Tsutsumi, T., K. Yoda, P. Sahunalu, P. Dhanmanonda and B. Prachaiyo. (1983). Forest: Felling burning and regeneration. In K. Kyuma and C. Pairintra (eds.). **Shifting cultivation: An experiment at Nam Phrom, Northeast Thailand and Its Implication for Upland Farming in the Monsoon Tropics.** Japan.

United States Environmental Protection Agency (EPA). (2000). **Global warming** [On-line]. Available: http://www.epa.gov/oppeoee1/globalwarming/kids /green house.html

University of Nebraska-Lincoln. (2000). **Greenhouse effect** [On-line]. Available: http:// pw2.netcom.com/~kmgenius/ge2gases.html

Vacharotayan, S. and A. Pintukanok. (1985). Agricultural and agro-industrial residues in Thailand. In S. Vacharotayan and T. Yoshida (eds.). **Utilization of Oganic Waste Materials in Agriculture with Reference of NRCT-JSPS Cooperative Research in Thailand** (PP 222-228), Tokyo.

Vijchulata, P. (1997). Greenhouse gas mitigation option in livestock sector. In **Greenhouse gas mitigation option.** TEI. Bangkok. Thailand.

Wanapat, M. (1986). **Ruminant nutrition.** Faculty of Agriculture. Khon Kaen University. Khon Kaen. Thailand.

Xu. Deying. (1992). Forest related CO_2 emissions in China: Current estimated and long-term forecast. In **Carbon emissions and sequestration in forests: Case studies from seven developing country.** Lawrence Berkeley Laboratory. Berkeley. California. USA.

APPENDIX A

Units & Abbreviations

Table A.1 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}	1,00
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}	0.0000001

Table A.2 Unit and abbreviations.

Unit	Symbol
cubic meter	m^3
degree celsius	^{O}C
dry matter	dm
gram	g
hectare	ha
joule	J
part per million	ppm
tonne of oil equivalent	toe
tonne	t
year	yr

APPENDIX B

General Definition

B. General Definition

Afforestation

Planting of new forests on lands which, historically, have not contained forests.

Biomass

Non-fossiled organic material both above ground and below ground, and both living and dead, e.g., trees, crops, grasses, tree litter, root etc. When burned for energy purposes, these are referred to as biomass fuels. Biomass fuels also include gases recovered from the decomposition of organic material.

Bunkers (international marine bunkers)

The quantities of fuel supplied to sea-going ships, whatever their flag and category. However, this does not cover amounts supplied for internal transport by water or coastal vessels, nor for air traffic, even international.

Carbon dioxide equivalent and carbon equivalent

The combined effect that all greenhouse gases exhibit toward the atmosphere is often expressed as an equivalent concentration of carbon dioxide to simplify matters. A carbon equivalent may also be used. Both are calculated based upon the global warming potential of the various gases.

Carbon-sequestration

The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the

Charcoal

A black, amorphous form of carbon made by heating wood or other organic matter in the absence of air.

Dairy cattle

Cattle producing milk for commercial exchange and calves and heifers grown for dairy purposes.

Deep water (rice fields)

Rice fields in lowland areas where flooding levels are higher than 50 cm.

Dry (rice fields)

Rice cultivation in both upland and lowland areas where there is no flooding during cropping period. Rice seeds are drilled in furrows and covered with light soil.

Dry matter (dm)

In this study dry matter refers to biomass which has dried to an oven dry state. This means that all loose water has been driven off but water that is part of the carbohydrate molecule and various volatiles still remains. By contrast, dry matter which is only air dry may contain 15% moisture.

Emission factor

A coefficient that relates the activity data to the amount of chemical compound which is the source of later emissions. Emission factors are offer based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.

Energy consumption

The utilization of energy for conversion to secondary energy or the production of useful energy. It should be stated whether the energy consumed is primary energy, secondary energy, energy supplied or useful energy.

Energy conversion

The recovery or production of energy involving no change in the physical state of the form of energy (e.g., coke from coal).

Energy supplied (energy available or final energy)

The energy made available to the consumer before its final conversion (i.e. before final utilization).

Energy transformation

The recovery or production of energy involving a physical change of state of the form of energy (e.g., coal liquefaction). In English usage the term “energy conversion” is commonly employed in both this sense.

Energy use

Use of primary and/or derived energy for the production of useful energy. For statistical purposes, energy use is often broken down into consumer sectors (industrial, transport, agricultural, etc.) but from other purposes the breakdown may be according to use to which the energy is put; i.e., thermal use mechanical use, chemical use, lighting etc.

Final energy consumption

Energy consumed by the final users for all energy purposes.

Final non-energy consumption

Consumption by the final user of:

(1) "Energy products" used for non-energy purposes (e.g., naphtha or natural gas used in petrochemicals).

(2) "Non-energy products" resulting from the production of energy products (e.g., lubricants, white spirit, bitumen).

Flaring

The burning of gas which cannot be contained or used productively. In some cases, when associated natural gas is released along with oil from production fields remote from energy users, the gas is burned off as it escapes, primarily for safety reasons. Some flaring may also occur in the processing of oil and gas.

Fossil fuel

Fossil fuel comprises combustible fuels formed from organic matter within the earth's crust over geological time scales and products manufactured from them. The fuels extracts from the earth and prepared form market are termed "Primary fuels" (e.g. coal, natural gas, crude oil, lignite) and fuel products manufactured from them are termed "Secondary fuels" (e.g. coke, blast furnace gas, gas/diesel oil, etc.).

Fugitive emissions

Fugitive emissions are intentional or unintentional releases of gases from anthropogenic activities. In particular, they may arise from the production, processing , transmission, storage and use of fuels and include emissions form combustion only where it does not support a productive activity (e.g., flaring of natural gases at oil and gas production facilities).

Greenhouse gases

Gases that absorb infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone depleting substances, such as halogenated fluorocarbons (HCFCs), perfluorinated carbons (PFCs), hydrofluorocarbons (HFCs) etc.

Global warming potential (GWP)

GWP is the index used to compare the relative radiative forcing of various greenhouse gases without directly calculating the changes in atmospheric concentrations. It is essentially a ratio of how much one kilogram of specific greenhouse gas can change the balance between incoming solar radiation and outgoing infrared radiation to the amount that one kilogram of carbon dioxide can change this balance.

Gross domestic product (GDP)

The annual total of goods produced, and services provided, in a country

Irrigated (rice fields)

Rice field receive water both from irrigation systems and pumped from other natural resources such as rivers and canals.

Manure

Waste materials, produced by domestic livestock, which are managed for agricultural purposes. When manure is managed in a way that involves anaerobic decomposition, significant emissions of methane can result.

Major rice

Major rice is rice that is planted in the wet season, usually during July to August, and harvested in November to December.

Non-dairy cattle

All cattle which are not dairy cattle, including cattle kept or reared for key production, draft animals and breeding animals.

Non-energy use

Non-energy use covers use of other petroleum product such as white spirit, paraffin waxes, lubricants, bitumen and other products. They are shown separately under the heading non-energy use and are included in total final consumption. It is assumed that the use of these products is exclusively non-energy use. An exception to this treatment is the petroleum coke which is shown as non-energy use only when there is evidence of such use; otherwise it is shown under energy use in industry or in other sectors. Non-energy use of coal includes carbon blacks, graphite electrodes, etc..

Own use

Own use contains the primary and secondary energy consumed by transformation industries for heating, pumping, traction and lighting. These are shown as negative figures. Included here are, for example, coal mines' own use of energy, power plant's own consumption (which includes net electricity consumed for pumped storage), and energy used for oil and gas extraction.

Primary energy

Energy embodied in natural resources (e.g., coal, crude oil, sunlight, uranium) that has not undergone any anthropogenic conversion of transformation.

Rainfed (rice fields)

Rice fields in all areas under flooding levels not higher than 50 cm.

Secondary energy (derived energy)

Energy that has been produced by the conversion or transformation of primary energy or of another secondary from of energy

Second rice

Second rice is rice that is planted after harvesting the major rice, normally during November to June.

Sequestration

The process of increasing the carbon content of a carbon pool other than the atmosphere

Sink

A reservoir that uptakes a chemical element or compound from another part of its cycles. For example, soil and trees tend to act as natural sinks for carbon. Any process or activity that releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas into the atmosphere.

Stock change

The difference between the quantities of energy stocked by producers, importers, distributors, energy conversion plants and large industrial consumers at the beginning and end of the period under consideration. This difference should be allocated an algebraic symbol (+ or -) the sense of which should always be specified by the compiler of the balance: + can indicate either an increase or decrease in stock.

APPENDIX C

Emission of carbon dioxide, methane and nitrous oxide from various sector in Thailand

Table C.1 Emission of CO_2, CH_4 and N_2O from various sub-sectors in Thailand in 1990 (Gg)

Gas/Source	Emission		GWP	Emission (CO_2 equivalent)	
	Gg-Gas	%		Gg-Gas	%
Total CO_2 equivalent				315577.05	100.00
Net Carbon dioxide (CO_2)	219426.67	100.00	1	219426.67	69.53
Fuel Combustion					
Power	28242.00	12.87		28242.00	8.95
Agriculture	5552.00	2.53		5552.00	1.76
Residential & Commercial	20182.00	9.20		20182.00	6.40
Industry, Mining and Construction	31650.00	14.42		31650.00	10.03
Transport	34476.73	15.71		34476.73	10.92
Industrial Process	9374.70	4.27		9374.70	2.97
Forest					
Change in Forest and Other Wooddy	27769.27	12.66		27769.27	8.80
Biomass Stocks					
Emission	28695.88			28695.88	
Removal	-926.61			-926.61	
Forest Conversion	87595.42	39.92		87595.42	27.76
Abandonment of Managed Land	-25415.45	-11.58		-25415.45	-8.05
Methane (CH_4)	4055.67	100.00	21	85168.97	26.99
Fuel Combustion					
Power	0.60	0.015		12.60	0.00
Agriculture	0.76	0.019		15.96	0.01
Residential & Commercial	47.15	1.163		990.15	0.31
Industry and Construction	4.28	0.106		89.88	0.03
Transport	2.50	0.062		52.50	0.02
Fugitive Emissions					
Coal	10.41	0.257		218.51	0.07
Oil and Natural Gas	94.37	2.327		1981.83	0.63
Agriculture					
Livestock	568.97	14.029		11948.35	3.79
Rice Cultivation	2847.15	70.202		59790.15	18.95
Field Burning of Agricultural Residues	21.04	0.519		441.87	0.14
Forest					
Forest Conversion	30.94	0.763		649.74	0.21
Waste					
Solid waste Disposal on Land	131.31	3.238		2757.51	0.87
Wastewater Treatment	296.19	7.303		6219.93	1.97
Nitrous Oxide (N_2O)	35.42	100.00	310	10981.41	3.48
Fuel Combustion					
Power	0.23	0.65		71.30	0.02
Agriculture	0.05	0.14		15.50	0.00
Residential & Commercial	0.51	1.44		158.10	0.05
Industry and Construction	0.61	1.72		189.10	0.06
Transport	0.25	0.71		77.50	0.02
Agriculture					
Field Burning of Agricultural Residues	0.47	1.34		146.91	0.05
Agricultural Soils	33.09	93.41		10257.90	3.25
Forest					
Forest Conversion	0.21	0.59		65.10	0.02

Table C.2 Emission of CO_2, CH_4 and N_2O from various sub-sectors in Thailand in 1995 (Gg)

Gas/Source	Emission		GWP	Emission (CO_2 equivalent)	
	Gg-Gas	%		Gg-Gas	%
Total CO_2 equivalent				366021.35	100.00
Net Carbon dioxide (CO_2)	261938.02	100.00	1	261938.02	71.56
Fuel Combustion					
Power	52053.00	19.87		52053.00	14.22
Agriculture	4841.00	1.85		4841.00	1.32
Residential & Commercial	35081.00	13.39		35081.00	9.58
Industry, Mining and Construction	56397.00	21.53		56397.00	15.41
Transport	56974.00	21.75		56974.00	15.57
Industrial Process	17577.90	6.71		17577.90	4.80
Forest					
Change in Forest and Other Wooddy	29040.37	11.09		29040.368	7.93
Biomass Stocks					
Emission	29603.66			29603.66	
Removal	-563.29			-563.29	
Forest Conversion	34172.30	13.05		34172.30	9.34
Abandonment of Managed Land	-24198.54	-9.24		-24198.54	-6.61
Methane (CH_4)	4354.95	100.00	21	91453.93	24.99
Fuel Combustion					
Power	1.55	0.04		32.55	0.01
Agriculture	0.66	0.02		13.86	0.00
Residential & Commercial	78.01	1.79		1638.21	0.45
Industry and Construction	7.00	0.16		147.00	0.04
Transport	4.18	0.10		87.78	0.02
Fugitive Emissions					
Coal	15.43	0.35		323.93	0.09
Oil and Natural Gas	170.00	3.90		3569.98	0.98
Agriculture					
Livestock	613.38	14.08		12880.98	3.52
Rice Cultivation	2827.38	64.92		59374.98	16.22
Field Burning of Agricultural Residues	25.51	0.59		535.71	0.15
Forest					
Forest Conversion	12.07	0.28		253.47	0.07
Waste					
Solid waste Disposal on Land	208.26	4.78		4373.46	1.19
Wastewater Treatment	391.53	8.99		8222.03	2.25
Nitrous Oxide (N_2O)	40.74	100.00	310	12629.40	3.45
Fuel Combustion					
Power	0.42	1.03		130.20	0.04
Agriculture	0.04	0.10		12.40	0.00
Residential & Commercial	0.75	1.84		232.50	0.06
Industry and Construction	0.99	2.43		306.90	0.08
Transport	0.37	0.91		114.70	0.03
Agriculture					
Field Burning of Agricultural Residues	0.48	1.18		148.80	0.04
Agricultural Soils	37.59	92.27		11652.90	3.18
Forest					
Forest Conversion	0.10	0.25		31.00	0.01

Table C.3 Emission of CO_2, CH_4 and N_2O from various sub-sectors in Thailand in 1998 (Gg)

Gas/Source	Emission		GWP	Emission (CO_2 equivalent)	
	Gg-Gas	%		Gg-Gas	%
Total CO_2 equivalent				338508.38	100.00
Net Carbon dioxide (CO_2)	231502.94	100.00	1	231502.94	68.39
Fuel Combustion					
Power	58031.00	25.07		58031.00	17.14
Agriculture	5757.00	2.49		5757.00	1.70
Residential & Commercial	22675.00	9.79		22675.00	6.70
Industry, Mining and Construction	49081.00	21.20		49081.00	14.50
Transport	57096.00	24.66		57096.00	16.87
Industrial Process	12003.30	5.18		12003.30	3.55
Forest					
Change in Forest and Other Wooddy	30469.98	13.16		30469.98	9.00
Biomass Stocks					
Emission	30694.40			30694.40	
Removal	-224.42			-224.42	
Forest Conversion	18801.01	8.12		18801.01	5.55
Abandonment of Managed Land	-22411.35	-9.68		-22411.35	-6.62
Methane (CH_4)	4577.06	100.00	21	96118.18	28.39
Fuel Combustion					
Power	1.45	0.03		30.45	0.01
Agriculture	0.79	0.02		16.59	0.00
Residential & Commercial	50.18	1.10		1053.78	0.31
Industry and Construction	6.30	0.14		132.30	0.04
Transport	4.65	0.10		97.65	0.03
Fugitive Emissions					
Coal	16.89	0.37		354.69	0.10
Oil and Natural Gas	263.52	5.76		5533.92	1.63
Agriculture					
Livestock	394.46	8.62		8283.72	2.45
Rice Cultivation	3102.76	67.79		65157.96	19.25
Field Burning of Agricultural Residues	20.65	0.45		433.74	0.13
Forest					
Forest Conversion	6.64	0.15		139.44	0.04
Waste					
Solid waste Disposal on Land	284.44	6.21		5973.24	1.76
Wastewater Treatment	424.32	9.27		8910.70	2.63
Nitrous Oxide (N_2O)	35.12	100.00	310	10887.26	3.22
Fuel Combustion					
Power	0.42	1.20		130.20	0.04
Agriculture	0.05	0.14		15.50	0.00
Residential & Commercial	0.54	1.54		167.40	0.05
Industry and Construction	0.88	2.51		272.80	0.08
Transport	0.38	1.08		117.80	0.03
Agriculture					
Field Burning of Agricultural Residues	0.40	1.14		124.06	0.04
Agricultural Soils	32.40	92.25		10044.00	2.97
Forest					
Forest Conversion	0.05	0.14		15.50	0.00

APPENDIX D

Example of Calculation Worksheet for 1995

1. Energy

Table D.1.1 Calculation of CO_2 emission from fuel combustion by power sub-sector in 1995.

	MODULE	ENERGY						
	SUBMODULE	CO_2 FROM FUEL COMBUSTION BY SOURCE						
	WORKSHEET	POWER SECTOR						
	SHEET							
		STEP 1		STEP 2		STEP 3		STEP 4
		A Apparent Consumption [1] (TJ)	B Carbon Emission Factor [2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized [2]	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	D = (C×10^{-3})		F = (D×E)	G=(F×[44/12])
Liquid Fossil	Gasoline	0	18.9	0	0	0.990	0	0
	Jet Kerosene	0	19.5	0	0	0.990	0	0
	Kerosene	0	19.5	0	0	0.990	0	0
	Diesel Oil	27679.20	20.2	559120	559	0.990	554	2030
	Residual Oil	209389.05	21.1	4418109	4418	0.990	4374	16038
	LPG	0	17.2	0	0	0.990	0	0
Liquid Fossil Totals								
Solid Fossil	Anthracite	0	26.8	0	0	0.980	0	0
	Coking Coal	0	25.8	0	0	0.980	0	0
	Briquette & other coal	263.70	25.8	6803	7	0.980	7	24
	Lignite	142193.07	27.6	3924529	3925	0.980	3846	14102
Solid Fossil Totals								
Gaseous Fossil	Natural Gas	312897.24	15.3	4787328	4787	0.995	4763	17466
Total								
Biomass Total								
	Wood	287.82	30.02	8640	9	0.870	8	28
	Charcoal	0	30.12	0	0	0.880	0	0
	Paddy Husk	374.40	31.25	11700	12	0.880	10	38
	Bagasse	12070.59	59.76	721338	721	0.880	635	2328
							Total	52053

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.2 Calculation of CO_2 emission from fuel combustion by agriculture sub-sector in 1995.

	MODULE	ENERGY						
	SUBMODULE	CO_2 FROM FUEL COMBUSTION BY SOURCE						
	WORKSHEET	AGRICULTURE SECTOR						
	SHEET							
		STEP 1	STEP 2			STEP 3		STEP 4
		A Apparent Consumption[1] (TJ)	B Carbon Emission Factor[2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	D = (C×10^{-3})		F = (D×E)	G=(F×[44/12])
Liquid Fossil	Gasoline	2046.20	18.9	38673	39	0.990	38	140
	Jet Kerosene	0	19.5	0	0	0.990	0	0
	Kerosene	34.53	19.5	673	1	0.990	1	2
	Diesel Oil	63188.70	20.2	1276412	1276	0.990	1264	4633
	Residual Oil	755.63	21.1	1831	16	0.990	16	58
	LPG	106.48	17.2	0	2	0.990	2	7
Liquid Fossil Totals								
Solid Fossil	Anthracite	0	26.8	0	0	0.980	0	0
	Coking Coal	0	25.8	0	0	0.980	0	0
	Briquette & other coal	0	25.8	0	0	0.980	0	0
	Lignite	0	27.6	0	0	0.980	0	0
Solid Fossil Totals								
Gaseous Fossil	Natural Gas	0	15.3	0	0	0.995	0	0
Total								
Biomass Total								
	Wood	0	30.02	0	0	0.870	0	0
	Charcoal	0	30.12	0	0	0.880	0	0
	Paddy Husk	0	31.25	0	0	0.880	0	0
	Bagasse	0	59.76	0	0	0.880	0	0
							Total	4841

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.3 Calculation of CO_2 emission from fuel combustion by residential & commercial sub-sector in 1995.

MODULE		ENERGY						
SUBMODULE		CO_2 FROM FUEL COMBUSTION BY SOURCE						
WORKSHEET		RESIDENTIAL & COMMERCIAL						
SHEET								
		STEP 1	STEP 2			STEP 3		STEP 4
		A Apparent Consumption[1] (TJ)	B Carbon Emission Factor[2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	D = (C×10^{-3})		F = (D×E)	G=(F×[44/12])
Liquid Fossil	Gasoline	0	18.9	0	0	0.990	0	0
	Jet Kerosene	0	19.5	0	0	0.990	0	0
	Kerosene	1519.32	19.5	29627	30	0.990	29	108
	Diesel Oil	254.94	20.2	5150	5	0.990	5	19
	Residual Oil	5885.96	21.1	124194	124	0.990	123	451
	LPG	53346.48	17.2	917559	918	0.990	908	3331
Liquid Fossil Totals								
Solid Fossil	Anthracite	0	26.8	0	0	0.980	0	0
	Coking Coal	0	25.8	0	0	0.980	0	0
	Briquette & other coal	0	25.8	0	0	0.980	0	0
	Lignite	0	27.6	0	0	0.980	0	0
Solid Fossil Totals								
Gaseous Fossil	Natural Gas	0	15.3	0	0	0.995	0	0
Total								
Biomass Total								
	Wood	128719.50	30.02	3864159	3864	0.870	3362	12327
	Charcoal	193871.44	30.12	5839408	5839	0.880	5139	18842
	Paddy Husk	43.20	31.25	1350	1	0.880	1	4
	Bagasse	0	59.76	0	0	0.880	0	0
							Total	35081

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.4 Calculation of CO_2 emission from fuel combustion by industrial & construction sub-sector in 1995.

MODULE		ENERGY						
SUBMODULE		CO_2 FROM FUEL COMBUSTION BY SOURCE						
WORKSHEET		INDUSTRIAL & CONSTRUCTION						
SHEET								
		STEP 1	STEP 2			STEP 3		STEP 4
		A Apparent Consumption[1] (TJ)	B Carbon Emission Factor[2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	D = (C×10^{-3})		F = (D×E)	G=(F×[44/12])
Liquid Fossil	Gasoline	2864.68	18.9	54142	54	0.990	54	197
	Jet Kerosene	0	19.5	0	0	0.990	0	0
	Kerosene	1968.21	19.5	38380	38	0.990	38	139
	Diesel Oil	26295.24	20.2	531164	531	0.990	526	1928
	Residual Oil	153551.97	21.1	3239947	3240	0.990	3208	11761
	LPG	11819.28	17.2	203292	203	0.990	201	738
Liquid Fossil Totals								
Solid Fossil	Anthracite	376.80	26.8	10098	10	0.980	10	36
	Coking Coal	2763.00	25.8	71285	71	0.980	70	256
	Briquette & other coal	60835.59	25.8	1569558	1570	0.980	1538	5640
	Lignite	51460.05	27.6	1420297	1420	0.980	1392	5104
Solid Fossil Totals								
Gaseous Fossil	Natural Gas	33051.06	15.3	505681	506	0.995	503	1845
Total								
Biomass Total								
	Wood	31228.47	30.02	937479	937	0.870	816	2991
	Charcoal	0	30.12	0	0	0.880	0	0
	Paddy Husk	24667.20	31.25	770850	771	0.880	678	2487
	Bagasse	120284.22	59.76	7188185	7188	0.880	6326	23194
							Total	56316

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.5 Calculation of CO_2 emission from fuel combustion by mining sub-sector in 1995.

	MODULE	ENERGY						
	SUBMODULE	CO_2 FROM FUEL COMBUSTION BY SOURCE						
	WORKSHEET	MINING						
	SHEET							
		STEP 1	STEP 2			STEP 3		STEP 4
		A Apparent Consumption[1] (TJ)	B Carbon Emission Factor[2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	$D = (C\times10^{-3})$		F = (D×E)	G=(F×[44/12])
Liquid Fossil	Gasoline	0	18.9	0	0	0.990	0	0
	Jet Kerosene	0	19.5	0	0	0.990	0	0
	Kerosene	0	19.5	0	0	0.990	0	0
	Diesel Oil	1019.76	20.2	20599	21	0.990	20	75
	Residual Oil	79.54	21.1	1678	2	0.990	2	6
	LPG	0	17.2	0	0	0.990	0	0
Liquid Fossil Totals								
Solid Fossil	Anthracite	0	26.8	0	0	0.980	0	0
	Coking Coal	0	25.8	0	0	0.980	0	0
	Briquette & other coal	0	25.8	0	0	0.980	0	0
	Lignite	0	27.6	0	0	0.980	0	0
Solid Fossil Totals								
Gaseous Fossil	Natural Gas	0	15.3	0	0	0.995	0	0
Total								
Biomass Total								
	Wood	0	30.02	0	0	0.870	0	0
	Charcoal	0	30.12	0	0	0.880	0	0
	Paddy Husk	0	31.25	0	0	0.880	0	0
	Bagasse	0	59.76	0	0	0.880	0	0
							Total	81

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.6 Calculation of CO_2 emission from fuel combustion by transportation sub-sector in 1995.

MODULE		ENERGY						
SUBMODULE		CO_2 FROM FUEL COMBUSTION BY SOURCE						
WORKSHEET		TRANSPORTATION SECTOR						
SHEET								
		STEP 1	STEP 2			STEP 3		STEP 4
		A Apparent Consumption[1] (TJ)	B Carbon Emission Factor[2] (t-C/TJ)	C Carbon Content (t-C)	D Carbon Content (Gg-C)	E Fraction of Carbon Oxidized	F Actual Carbon Emissions (Gg-C)	G Actual CO_2 Emissions (Gg-CO_2)
FUEL TYPES				C = (A×B)	D = (C×10^{-3})		F = (D×E)	G=(F×[44/12])
Road	Gasoline	192374.28	18.90	3635873.89	3635.87	0.990	3599.52	13198.22
	Diesel Oil	427170.18	20.20	8628837.64	8628.84	0.990	8542.55	31322.68
	LPG	6442.04	17.20	110803.09	110.80	0.990	109.70	402.22
	Natural Gas	139.74	15.30	2138	2.14	0.995	2.13	7.80
Rail	Gasoline	0	18.90	0.00	0.00	0.990	0.00	0.00
	Diesel Oil	4843.86	20.20	97845.97	97.85	0.990	96.87	355.18
Air	Jet Kerosene	109563.69	19.50	2136491.96	2136.49	0.990	2115.13	7755.47
Waterway	Gasoline	818.48	18.90	15469.27	15.47	0.990	15.31	56.15
	Diesel Oil	17882.22	20.20	361220.84	361.22	0.990	357.61	1311.23
	Residual Oil	33486.34	21.10	706561.77	706.56	0.990	699.50	2564.82
							Total	56974

Sources: 1. Department of Energy Development and Promotion (1999).
2. IPCC (1996a).

Table D.1.7 Calculation of CH_4 emission from fuel combustion by difference sub-sector in 1995.

MODULE		ENERGY						
SUBMODULE		CH_4 FROM FUEL COMBOSTION BY SOURCE						
WORKSHEET								
SHEET		1 OF 3						
		STEP 1						
Sector		A Energy Consumption [1] (TJ)						
		A1	A2	A3		A4	A5	A6
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass
Power		142456.77	312897.24	237068.25		287.82	0	12444.99
Agriculture		0	0	66131.54		0	0	0
Residential & Commercial		0	0	61006.70		128719.50	193871.44	43.20
Industrial and Construction		115435.44	33051.06	96499.38		31228.47	0	144951.42
				Gasoline	Diesel			
Transportation	Road	0	139.74	192374.28	427170.18	0	0	0
	Rail	0	0	4843.86		0	0	0
	Air	0	0	109563.69		0	0	0
	Waterway	0	0	52187.04		0	0	0

Source: 1. DEDP (1999).

Table D.1.7 Calculation of CH_4 emission from fuel combustion by difference sub-sector in 1995 (cont.).

MODULE		ENERGY						
SUBMODULE		CH_4 EMISSIONS FROM FUEL COMBOSTION BY SOURCE						
WORKSHEET								
SHEET		2 OF 3						
		STEP 2						
Sector		B Emission Factors [1] (kg- CH_4/TJ)						
		B1	B2	B3		B4	B5	B6
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass
Power		1	1	3		30	200	30
Agriculture		0	0	10		0	0	0
Residential & Commercial		0	0	10		300	200	300
Industrial and Construction		10	5	2		30	200	30
Transportation	Road	0	50	Gasoline 20	Diesel 5	0	0	0
	Rail	0	0	5		0	0	0
	Air	0	0	0.5		0	0	0
	Waterway	0	0	5		0	0	0

Source: 1. IPCC (1996a).

Table D.1.7 Calculation of CH_4 emission from fuel combustion by difference sub-sector in 1995 (cont.).

MODULE		ENERGY							
SUBMODULE		CH_4 EMISSIONS FROM FUEL COMBOSTION BY SOURCE							
WORKSHEET									
SHEET		3 OF 3							
		STEP 3							
Sector		C Actual CH_4 Emissions (kg-CH_4)							D Total Emissions (Gg-CH_4)
		C = (A×B)							D= $(C1+…+C6)/10^6$
		C1	C2	C3		C4	C5	C6	
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass	
Power		142456.77	312897.24	711204.75		8634.6	0	373349.7	1.55
Agriculture		0	0	661315.4		0	0	0	0.66
Residential & Commercial		0	0	610067		38615850	38774288	12960	78.01
Industrial and Construction		1154354.4	165255.3	392998.76		936854.1	0	4348542.6	7.00
				Gasoline	Diesel				
Transportation	Road	0	50	3847485.6	213585.9	0	0	0	3.85
	Rail	0	0	24219.3		0	0	0	0.02
	Air	0	0	54781.845		0	0	0	0.05
	Waterway	0	0	260935.2		0	0	0	0.26
Total		1296811.17	478202.54	8698858.755		39561338.7	38774288	4734852.3	91.41

Table D.1.8 Calculation of N_2O emission from fuel combustion by difference sub-sector in 1995.

MODULE		ENERGY						
SUBMODULE		N_2O FROM FUEL COMBOSTION BY SOURCE						
WORKSHEET								
SHEET		1 OF 3						
		STEP 1						
Sector		A Energy Consumption [1] (TJ)						
		A1	A2	A3		A4	A5	A6
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass
Power		142456.77	312897.24	237068.25		287.82	0	12444.99
Agriculture		0	0	66131.54		0	0	0
Residential & Commercial		0	0	61006.70		128719.50	193871.44	43.20
Industrial and Construction		115435.44	33051.06	96499.38		31228.47	0	144951.42
				Gasoline	Diesel			
Transportation	Road	0	139.74	192374.28	427170.18	0	0	0
	Rail	0	0	4843.86		0	0	0
	Air	0	0	109563.69		0	0	0
	Waterway	0	0	52187.04		0	0	0

Source: 1. DEDP (1999).

Table D.1.8 Calculation of N_2O emission from fuel combustion by difference sub-sector in 1995 (cont.).

MODULE	ENERGY
SUBMODULE	N_2O EMISSIONS FROM FUEL COMBOSTION BY SOURCE
WORKSHEET	
SHEET	2 OF 3
	STEP 2

Sector		STEP 2 B Emission Factors [1] (kg- N_2O/TJ)						
		B1	B2	B3		B4	B5	B6
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass
Power		1.4	0.1	0.6		4	4	4
Agriculture		0	0	0.6		0	0	0
Residential & Commercial		0	0	0.6		4	1	4
Industrial and Construction		1.4	0.1	0.6		4	4	4
				Gasoline	Diesel			
Transportation	Road	0	0.1	0.6	0.6	0	0	0
	Rail	0	0	0.6		0	0	0
	Air	0	0	2		0	0	0
	Waterway	0	0	0.6		0	0	0

Source: 1. IPCC (1996a).

Table D.1.8 Calculation of N_2O emission from fuel combustion by difference sub-sector in 1995 (cont.).

MODULE	ENERGY
SUBMODULE	N_2O EMISSIONS FROM FUEL COMBOSTION BY SOURCE
WORKSHEET	
SHEET	3 OF 3

Sector		STEP 3							
		C Actual CH_4 Emissions (kg- N_2O)							D Total Emissions (Gg-CH_4)
		C = (A×B)							D= $(C1+…+C6)/10^6$
		C1	C2	C3		C4	C5	C6	
		Coal	Natural Gas	Oil		Wood	Charcoal	Other Biomass	
Power		199439.478	31289.724	142240.95		1151.28	0	49779.96	0.42
Agriculture		0	0	39678.924		0	0	0	0.04
Residential & Commercial		0	0	36604.02		514878	193871.44	172.8	0.75
Industrial and Construction		161609.616	3305.106	117899.628		124913.88	0	579805.68	0.99
Transportation	Road	0	13.974	Gasoline 115424.568	Diesel 256302.108	0	0	0	0.12
	Rail	0	0	2906.316		0	0	0	0.00
	Air	0	0	219127.38		0	0	0	0.22
	Waterway	0	0	31312.224		0	0	0	0.03
Total		361049.094	34608.804	961496.118		640943.16	193871.44	629758.44	2.57

Table D.1.9 Calculation of CH_4 emission from fugitive emission by coal production in 1995.

MODULE		ENERGY							
SUBMODULE		CH_4 FROM FUGITIVE EMISSION							
WORKSHEET		COAL PRODUCTION							
SHEET									
		A Amount of Coal Produced [1] (million –t)	B Emission Factor [2] (m^3-CH_4/t)		C Methane Emissions (million m^3) C = A×B		D Conversion Factors (0.67 Gg [2] $CH_4/10^6$ m^3)	E Methane Emissions (Gg-CH_4) E = C×D	
			Low	High	Low	High		Low	High
Surface Mines	Mining	18.416	0.30	2.00	5.525	36.832	0.67	3.70	24.68
	Post-Mining	18.416	0.00	0.20	0.000	3.683	0.67	0.00	2.47
							Total	3.70	27.15
							Average	15.425	

Sources: 1. DEDP (1999).
2. IPCC (1996a).

Table D.1.10 Calculation of CH_4 emission from fugitive emission by oil and natural gas production in 1995.

MODULE	ENERGY						
SUBMODULE	CH_4 FROM FUGITIVE EMISSION						
WORKSHEET	OIL AND NATURAL GAS PRODUCTION						
SHEET							
Category	A Activity [1] PJ	B Emission Factor [2] Kg/PJ		C CH_4Emissions Kg-CH_4 C = A×B		D CH_4Emissions Gg-CH_4 $D = C/10^6$	
		Low	High	Low	High	Low	High
OIL							
Production	50.26	300	5000	15077.02	251283.75	0.015	0.251
Refining	50.26	90	1400	4523.11	70359.45	0.005	0.070
				TOTAL CH_4 FROM OIL		0.020	0.322
GAS							
Production	417.27	46000	96000	19194364.80	40057804.80	19.194	40.058
Processing	417.27		288000		120173414.40		120.173
				TOTAL CH_4 FROM GAS		19.194	160.231
VENTING AND FLARING FROM OIL/GAS PRODUCTION							
Natural gas	417.27	175000	209000	73022040.00	87269179.20	73.022	87.209
			TOTAL CH_4 EMISSIONS FROM OIL AND GAS			92.236	247.762
			Average			170	

Sources: 1. DEDP (1999).
2. IPCC (1996a).

2. Industrial Processes

Table D.2.1 Calculation of CO_2 emission from industrial process in 1995.

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	CO_2 FROM INDUSTRIAL PROCESS			
WORKSHEET				
SHEET				
	STEP 1			STEP 2
	A Amount Produced[1]	B Emission Factor[2] (t-CO_2/t-produced)	C CO_2 emitted (t)	D CO_2 emitted (Gg)
			C = (AxB)	D = (C/1000)
Cement (tonne)	34051000	0.4985	16974423	16974.4
Glass (tonne)	463122	0.2026	93828	93.8
Lime (tonne)	154595	0.7857	121465	121.5
Paper Pulp (tonne)	299862	0.2072	62131	62.1
Iron and Steel (tonne)	1974162	0.0099	19544	19.5
Bakery (tonne)	2376788.8	0.000008[3]	19.01	0.019
Beer (thousand tonne)	647309	0.0272	17606	17.6
Wine (thousand tonne)	493735.5	0.0815	40239	40.2
Whisky (thousand tonne)	844920	0.2718	229649	229.6
			Total	17578

Source: 1. Bank of Thailand (2000).
2. Kessmanee C. (1997).
3. IPCC (1996a).

3. Agriculture

Table D.3.1 Calculation of CH_4 emission from agriculture activities by livestock sub-sector in 1995.

	MODULE	AGRICULTURE				
	SUBMODULE	CH_4 FROM LIVESTOCK				
	WORKSHEET					
	SHEET					
Livestock Type	A Number of Animals [1]	B Emissions Factor for Enteric Fermentation (kg/head/year)	C Emissions from Enteric Fermentation (kg/year)	D Emissions Factor for Manure Management (kg/head/year)	E Emission from Manure Management (kg/year)	F Total Annual Emissions From Domestic Livestock (Gg)
			C = (A×B)		E = (A×D)	$F = (C+E)/10^6$
Ruminant animals						
Dairy cattle	287247		17606103.63		2567349.842	20.173
Dairy cow	167187	76.957	12866209.96	11.222	1876172.514	14.742
Dairy female 0-1 yr	38502	25.067	965129.634	3.655	140724.810	1.106
Dairy female 1-2 yr	41900	43.548	1824661.2	6.350	266065.000	2.091
Haifer > 2yr	39658	49.173	1950102.834	7.171	284387.518	2.234
Non-dairy cattle	7321821		316579252.6		11379416.779	327.959
Female	5052056					
Cow	2526028	48.344	122118309.5	1.738	4390237.090	126.509
Female, 0-1 yr	858850	24.061	20664780.31	0.865	742904.907	21.408
Female, 1-2 yr	858850	40.230	34551519.54	1.446	1241896.526	35.793
Female, > 2yr	808329	41.546	33582838.23	1.493	1206835.254	34.790
Male	2269765					
Bull	1134882	50.644	57474976.92	1.820	2065485.704	59.540
Male, 0-1 yr	385860	26.673	10292042.89	0.959	370039.708	10.662
Male, 1-2 yr	385860	47.387	18284746.24	1.703	657119.523	18.942
Male, > 2yr	363162	53.998	19610039.04	1.941	704898.066	20.315
Buffalo	3710061		196969751.9		7080431.783	204.050
Female	2522841					
Mature	1261421	57.366	72362662.17	2.062	2601049.566	74.964
Female, 0-1 yr	428883	26.673	11439597.64	0.959	411298.846	11.851
Female, 1-2 yr	428883	47.700	20457721.56	1.715	735534.433	21.193
Female, > 2yr	403655	50.069	20210584.01	1.800	726578.346	20.937
Male	1187220					
Mature	593610	69.770	41416152.96	2.508	1488773.278	42.905
Male, 0-1 yr	201827	31.617	6381174.326	1.136	229275.834	6.610
Male, 1-2 yr	201827	57.592	11623638.92	2.070	417782.549	12.041
Male, > 2yr	189955	68.849	13078220.28	2.475	470138.930	13.548
Goat	132400	5.000	662000	0.220	29128.000	0.691
Sheep	75329	5.000	376645	0.210	15819.090	0.392
Non-ruminant animals						
Swine	8561921	1.000	8561921	5.630	48203615.230	56.766
Horse	16875	18.000	303750	2.200	37125.000	0.341
Poultry	130958286	0.000	0	0.023	3012040.578	3.012
		Total	541059424.1		72324926.302	613.384

Source: Department of Livestock Development (1996).

Table D.3.2 Calculation of CH_4 emission from agriculture activities by rice cultivation sub-sector in 1995.

MODULE	AGRICULTURE				
SUBMODULE	CH_4 FROM RICE CULTIVATION				
WORKSHEET					
SHEET					
	STEP 1			STEP 2	
Water Management Regime	A Harvested Area [1] (Mha)	B Season Length [3] (days)	C Megahectar-Days (Mha-days)	D Emission Factor [4] (kg/ha-day)	E CH_4 Emission by Water Management (Gg)
			C = (A×B)		E = (C×D)
Major rice					
Irrigated	1.943	104	202.07	2.234	451.43
Rainfed	6.164	120	739.68	2.998	2217.56
Deep water	0.003	164	0.49	0.817	0.40
Dry	0.044	136	5.98	0.000	0.00
Second rice					
Irrigated	0.680 [2]	140	70.72	2.234	157.99
Total	8.834				2827.38

Source: 1. Office of Agricultural Economic (1999).
2. Office of Agricultural Economic (2000a).
3. Piyaboot V. (1994).
4. Samkgahn K. et al. (2000).

Table D.3.3 Calculation of CH_4 and N_2O emission from agriculture activities by field burning of agriculture residues sub-sector in 1995.

MODULE		AGRICULTURE						
SUBMODULE		CH_4 AND N_2O FROM FIELD BURNING OF AGRICULTURAL RESIDUES						
WORKSHEET								
SHEET		1 OF 3						
	STEP 1			STEP 2		STEP 3		
Crops	A Harvested [1] Area (ha)	B Productivity Figures (Tonnes of Residue/10^3ha)	C Quantity of Residue (Gg-biomass)	D Dry Matter Fraction	E Quantity of Dry Residue (Gg-dm)	F Fraction Burned [4] In Fields	G Fraction [4] Oxidised	H Total Biomass Burned (Gg-dm)
			C = (A×B)		E = (C×D)			H = (E×F×G)
Rice : North	1770.36	3.1250 [2]	5532.38	0.85 [4]	4702.52	0.25	0.90	1058.07
Rice : Northeast	4820.77	1.8750	9038.95	0.85	7683.11	0.25	0.90	1728.70
Rice : Central	1802.61	4.3750	7886.41	0.85	6703.45	0.25	0.90	1508.28
Rice : South	454.09	3.1250 [3]	1419.02	0.85	1206.17	0.25	0.90	271.39
Maize	8167.68	3.1250	25524.00	0.40	10209.60	0.25	0.90	2297.16
Sorghum	128.96	4.3750	564.20	0.94 [5]	530.35	0.25	0.90	119.33
Cassava	1245.12	4.3750	5447.40	0.70 [6]	3813.18	0.25	0.90	857.97
Sugar cane	984.96	1.6875	1662.12	0.71 [7]	1180.11	0.25	0.90	265.52
Mung bean	332.80	1.8750	624.00	0.80 [6]	499.20	0.25	0.90	112.32
Soy bean	275.04	3.1250	859.50	0.91 [5]	782.15	0.25	0.90	175.98
Groundnuts	96.80	3.7500	363.00	0.80 [6]	290.40	0.25	0.90	65.34
							Total	8460.05

Sources: 1. Office of Agricultural Economic (2000a).
2. Tanyadee P. (1986).
3. Piriyapan V. (1982).
4. IPCC (1996a).
5. Wanapat M. (1986).
6. TDRI & TEI (1993).
7. KMITT (1995).

Table D.3.3 Calculation of CH_4 and N_2O emission from agriculture activities by field burning of agriculture residues sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	CH_4 AND N_2O FROM FIELD BURNING OF AGRICULTURE RESIDUE			
WORKSHEET				
SHEET	2 OF 3			
	STEP 4		STEP 5	
Crops	I Carbon Fraction of Residue	J Total Carbon Released (Gg-C)	K Nitrogen-Carbon Ratio	L Total Nitrogen Released (Gg-N)
		J = (H×I)		L = (J×K)
Rice : North	0.4449 [1]	470.734	0.0072 [1]	3.389
Rice : Northeast	0.4449	769.099	0.0072	5.538
Rice : Central	0.4449	671.032	0.0072	4.831
Rice : South	0.4449	120.741	0.0072	0.869
Maize	0.4456	1023.614	0.0060	6.142
Sorghum	0.4900 [2]	58.471	0.0200 [2]	1.169
Cassava	0.4915 [2]	421.690	0.0400 [2]	16.868
Sugar cane	0.5268 [3]	139.878	0.0120 [3]	1.679
Mung bean	0.4385 [2]	49.252	0.0204 [2]	1.005
Soy bean	0.4385 [2]	77.168	0.0204 [2]	1.574
Groundnuts	0.3829 [2]	25.019	0.0104 [2]	0.260
Total		3826.699		43.324

Sources: 1. Pintukanok et al (1988).
2.TDRI &TEI (1993).
3. KMITT (1995).

Table D.3.3 Calculation of CH_4 and N_2O emission from agriculture activities by field burning of agriculture residues sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	CH_4 AND N_2O FROM FIELD BURNING OF AGRICULTURE RESIDUE			
WORKSHEET				
SHEET	3 OF 3			
STEP 6				
	M Emission Ratio [1]	N Emission (Gg-C or Gg-N)	O Conversion Ratio	P Emissions from Field Burning Of Agricultural Residues (Gg)
		N = (J×M)		P = (N×O)
CH_4	0.005	19.1335	16/12	25.5113
CO	0.060	229.6019	28/12	535.7378
		N = (L×M)		P = (N×O)
N_2O	0.007	0.3033	44/28	0.4766
NO_X	0.121	5.2422	46/14	17.2244

Sources: 1. IPCC (1996b).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995.

MODULE	AGRICULTURE							
SUBMODULE	AGRICULTURE SOILS							
WORKSHEET	CHEMICAL NITROGEN FERTILIZER CONSUMPTION BY CROP TYPE							
SHEET								
Crop Type	Consumption (100 tonnes fertilizer) by fertilizer grade [1]							
	21-0-0	46-0-0	16-20-0	16-16-16	15-15-15	13-13-21	Others	Total
Fertilizer consumption :								
Rice	139.120	334.775	495.102	328.555	0.000	0.000	204.344	1501.896
Upland crops	61.517	30.446	62.969	20.729	165.145	36.040	204.356	581.202
Fruit tree	11.553	35.114	0.000	0.000	215.656	26.160	484.900	773.383
Vegetables & Ornamental	58.671	66.321	49.971	0.000	79.882	28.965	173.022	456.832
Total	270.861	466.656	608.042	349.284	460.683	91.165	1066.622	3313.313
	Nitrogen content (100 tonnes N) by fertilizer grade							
Nitrogen content :								
Rice	29.215	153.997	79.216	52.569	0.000	0.000	20.434	335.431
Upland crops	12.919	14.005	10.075	3.317	24.772	4.685	20.436	90.208
Fruit tree	2.426	16.152	0.000	0.000	32.348	3.401	48.490	102.818
Vegetables & Ornamental	12.321	30.508	7.995	0.000	11.982	3.765	17.302	83.874
Total	56.881	214.662	97.287	55.885	69.102	11.851	106.662	612.331

Source: 1. Office of Agricultural Economic (2000b).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	AGRICULTURE SOILS			
WORKSHEET	NITROGEN PRODUCED FROM SYNTHETIC FERTILIZER, F_{SN}			
SHEET				
	STEP 1	STEP 2		STEP 4
Synthetic fertilizer application	A N_{FERT} N fertillizer applicationces (tonnes/yr)	B Fraction of[1] loss as NH_3+ NO_X	C Loss as NH_3+ NO_X (tonnes/yr)	D Net soil N input F_{SN} (t–N/yr)
			C = (A×B)	D = (A-C)
Rice	335430	0.1	33543	301887
Upland crops	90210	0.1	9021	81189
Fruit tree	102820	0.1	10282	92538
Vegetables & Ornamental	83870	0.1	8387	75483
Total	612330	0.1	61233	551097

Source: 1 IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE							
SUBMODULE	AGRICULTURE SOILS							
WORKSHEET	NITROGEN PRODUCED FROM ANIMAL MANURE, F_{AW}							
SHEET								
	STEP 1	STEP 2		STEP 3				STEP 4
Livestock Type	A Number of [1] animals	B Tentative [2] values for N excretion (kg-N/head/yr)	C Nitrogen Excretion (kg-N/yr)	D Fraction of N excreted during grazing	E Nitrogen excreted during grazing (kg-N/yr)	F Fraction of N excreted emitted as NH_3 and NO_X	G Nitrogen excreted emitted as NH_3 and NO_X (kg-N/yr)	H Manure N Used (corrected For NH_3 and NO_X emissions) F_{AW} (kg-N/yr)
			C = (A×B)		E = (C×D)		G = (C×F)	H = C-E-G
Dairy cattle	287247	60	17234820	0.2	3446964	0.2	3446964	10340892
Non-dairy Cattle	7321821	40	292872840	0.6	175723704	0.2	58574568	58574568
Buffalo	3710061	40	148402440	0.6	89041464	0.2	29680488	29680488
Swine	8561921	16	136990736	0	0	0.2	27398147.2	109592589
Poultry	130958286	0.6	78574972	0.44	34572988	0.2	15714994.32	28286990
Total	19881050		674075808		302785120			236475527

Sources: 1. Department of Livestock Development (1999).
2. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE						
SUBMODULE	AGRICULTURE SOILS						
WORKSHEET	NITROGEN PRODUCED FROM CROP RESIDUES, F_{CR}						
SHEET							
	STEP 1	STEP 2			STEP 3		
Type of Crop Residues	A Harvested [1] Area (ha)	B Crop Residues/ Planted Area (tonne/ha)	C Nitrogen [4] Content (kg-N/kg-dry Biomass)	D Crop N	E Fraction of crop residue removed from field	F Fraction of crop residue burned	G N input from crop residue F_{CR} (kg-N/yr)
				D = A×B×C			G = [D×(1-E) ×(1-F)] ×1000
Non-N fixing crops							
Rice straw							
North	1770360	3.125 [2]	0.0057	31535	0.45	0.25	13007997
Northeast	4820770	1.875	0.0057	51522	0.45	0.25	21252816
Central	1802610	4.375	0.0057	44953	0.45	0.25	18542942
South	454090	3.125 [3]	0.0057	8088	0.45	0.25	3336497
Maize	8167680	3.125	0.0080	204192	0.45	0.25	84229200
Sugar cane	984960	1.688	0.0049	8147	0.45	0.25	3360555
cassava	1245120	4.375	0.0123	67003	0.45	0.25	27638746
Sorghum	128960	4.375	0.0080	4514	0.45	0.25	1861860
N-fixing crops							
Groundnut	96800	3.750	0.0120	4356	0.45	0.25	1796850
Soybean	275040	3.125	0.0136	11689	0.45	0.25	4821795
Mungbean	332800	1.875	0.0104	6490	0.45	0.25	2676960
Total	20079190			442488			182526219

Sources: 1. Office of Agricultural Economic (2000a).
2. Tanyadee P. (1986).
3. Piriyapan V. (1982).
4. Vacharotayan, S. and A. Pintukanok (1985).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	AGRICULTURE SOILS			
WORKSHEET	N FIXED BY N-FIXING CROPS IN COUNTRY, F_{BN}			
SHEET				
	STEP 1	STEP 2		STEP 4
Crop Type	A Edible Crop Yield (tonnes/yr)	B Fraction of N [1] in N-fixing crops	C Crop N	D Biological N fixation F_{BN} (t–N/yr)
			C = (A×B)	D = C×2
Soybeans	368000	0.03	11040	22080
Mungbeans	234000	0.03	7020	14040
Groundnuts	147000	0.03	4410	8820
Total	749000	0.03	22470	44940

Source: 1. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE		
SUBMODULE	AGRICULTURE SOILS		
WORKSHEET	NITROUS OXIDE EMISSION FROM DIRECT SOURCES, N_2O_{Direct}		
SHEET			
	STEP 1	STEP 2	
Type of N input to soil	A Amount of N Input (kg-N/yr)	B Emission Factor [1] for direct emissions (kg-N_2O-N/kg-N)	C Direct Soil Emissions, N_2O_{Direct} (Gg-N_2O)
			$C = AxBx(44/28)x10^{-6}$
Synthetic fertilizer (F_{SN})	551097000	0.0125	10.83
Animal waste (F_{AW})	236475527	0.0125	4.65
N-fixing crops (F_{BN})	44940000	0.0125	0.88
Crop residue (F_{CR})	182526219	0.0125	3.59
Total	1015038745	0.0125	19.94

Source: 1. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE					
SUBMODULE	AGRICULTURE SOILS					
WORKSHEET	NITROGEN PRODUCED FROM GRAZING ANIMAL, $N_2O_{Grazing\ Animal}$					
SHEET						
	STEP 1	STEP 2		STEP 3	STEP 4	STEP 5
Livestock Type	A Number of Animals, N_T (head)	B Tentative[1] values for N excretion, $N_{ex(T)}$ (kg-N/head/yr)	C Fraction of[1] N excreted during grazing, $Frac_{Graz}$	D Nitrogen excretion N_{ex} (kg-N/yr)	E Emission[1] Factor, EF_2 (kg-N_2O-N/kg/N)	F Nitrogen Excretion $N_2O_{Grazing\ Animal}$ (kg-N_2O/yr)
				D = A×B×C		F = E×(44/28) ×10^{-6}
Dairy cattle	287247	60	0.2	3446964	0.02	0.11
Non-dairy Cattle	7321821	40	0.6	175723704	0.02	5.52
Buffalo	3710061	40	0.6	89041464	0.02	2.80
Swine	8561921	16	0	0	0.02	0.00
Poultry	130958286	0.6	0.44	34572988	0.02	1.09
Total				302785120	0.02	9.52

Source: 1. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE				
SUBMODULE	AGRICULTURE SOILS				
WORKSHEET	NITROUS OXIDE EMISSION FROM NH_3 AND NO_X VOLATILIZATION, $N_2O_{(G)}$				
SHEET					
	STEP 1	STEP 2		STEP 3	
Source	A Amount of N Input (kg-N/yr)	B Fraction of[1] applied N that volatilizes	C Amount of N that loss as NH_3+No_x (kg-N/yr)	D Emission[1] factor (kg-N_0O-N/kg-N)	E Total N_2O Emission, $N_2O_{(G)}$ (Gg-N_2O)
			C = (AxB)		E = CxDx(44/28)x10^{-6}
Synthetic fertilizer	612330000	0.1	61233000	0.01	0.96
N excretion from Animal manure	674075808	0.2	134815162	0.01	2.12
Total	809145911		196048162	0.01	3.08

Source: 1. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	AGRICULTURE SOILS			
WORKSHEET	NITROUS OXIDE EMISSION FROM LEACHED/RUNOFF NITROGEN, $N_2O_{(C)}$			
SHEET				
	STEP 1	STEP 2		STEP 4
Source	A Amount of Nitrogen Input (kg-N/yr)	B Fraction of [1] N that Leached	C Emission [1] factor (kg-N_2O-N/kg-N)	D Total N_2O Emission, $N_2O_{(L)}$ (Gg- N_2O)
				$D = A \times B \times C \times (44/28) \times 10^{-6}$
Synthetic fertilizer	612330000	0.1	0.025	2.41
N excretion from Animal manure	674075808	0.1	0.025	2.65
Total	809145911	0.1	0.025	5.05

Source: 1. IPCC (1996a).

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE		
SUBMODULE	AGRICULTURE SOILS		
WORKSHEET	NITROUS OXIDE EMISSION FROM INDIRECT SOURCE, $N_2O_{Indirect}$		
SHEET			
	STEP 1	STEP 2	STEP 3
Source	A N_2O emission From Atmospheric Deposition (Gg- N_2O /yr)	B N_2O emission From Leaching (Gg- N_2O /yr)	C Indirect soil Emissions, $N_2O_{Indirect}$ (Gg-N_2O/yr)
			C = (A+B)
Synthetic fertilizer	0.96	2.41	3.37
N excretion from Animal manure	2.12	2.65	4.77
Total	3.08	5.05	8.13

Table D.3.4 Calculation of N_2O emission from agriculture activities by agriculture soils sub-sector in 1995 (cont.).

MODULE	AGRICULTURE			
SUBMODULE	AGRICULTURE SOILS			
WORKSHEET	TOTAL EMISSION OF NITROUS OXIDE FROM AGRICULTURAL SOILS			
SHEET				
	STEP 1	STEP 2	STEP 3	STEP 4
Source of N_2O emissions	A N_2O emission from direct sources (Gg- N_2O /yr)	B N_2O emission from Grazing animals (Gg- N_2O /yr)	C N_2O emission from Indirect sources (Gg-N_2O/yr)	D Total Nitrous oxide emissions (Gg-N_2O/yr)
				D = (A+B+C)
Synthetic fertilizer	10.83		3.37	14.19
Animals	4.65	9.52	4.77	18.93
Crops	4.47			4.47
Total	19.94	9.52	8.13	37.59

4. Forest

Table D.4.1 Calculation of CO_2 emission from forest by changes in forest and other woody biomass stocks in 1995.

MODULE	LAND USE CHANGE AND FORESTRY				
SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS				
WORKSHEET	ANNUAL BIOMASS C UPTAKE				
SHEET	1 OF 3				
	STEP 1				
Plantation	A Area of Forest/Biomass [1] (kha), AP	B Annual Growth rate (t-dm/ha), GP	C Annual biomass Increment (kt-dm)	D Carbon fraction of Dry [2] ,CP	E Total Carbon Uptake (kt-C), C_r
			C = (A×B)		E = (C×D)
dv.				0.5	
Pure stand					
Tectona grandis	7.052	15.40	108.606	0.5	54.303
Pinus sp.	3.342	10.90	36.426	0.5	18.213
Eucalyptus sp.	3.627	17.37	63.001	0.5	31.501
Petrocarpus macrocarpus	1.360	6.80	9.248	0.5	4.624
L.leucocephala	0.838	9.61	8.049	0.5	4.024
Acacia mangium	0.069	6.83	0.470	0.5	0.235
A. auriculiformis	0.058	9.39	0.549	0.5	0.274
A. catechu	0.161	15.00	2.410	0.5	1.205
Casaurina junghuhniana	0.327	12.50	4.087	0.5	2.043
Azadirachta indica	0.161	8.26	1.327	0.5	0.664
Rhizophora sp.	0.022	14.78	0.329	0.5	0.165
Hevea brasiliensis	0.358	14.50	5.195	0.5	2.597
Others	3.475	12.50	43.434	0.5	21.717
Misc	0.107	6.80	0.728	0.5	0.364
Mixed stand					
Teak and others	0.801	12.50	10.017	0.5	5.009
Euclyptus and others	0.294	14.50	4.267	0.5	2.133
Pinus sp. + Other	0.301	14.50	4.358	0.5	2.179
Acacia sp. And others	0.003	14.50	0.051	0.5	0.025
Peltophorum + others	0.033	6.80	0.227	0.5	0.114
Azadirachta sp. + Other	0.178	14.50	2.582	0.5	1.291
Teak and Pterocarpus	0.036	11.10	0.401	0.5	0.201
Teak and Eucalyptus	0.033	16.40	0.548	0.5	0.274
Anacardium + other	0.030	14.50	0.434	0.5	0.217
Others	0.041	12.50	0.507	0.5	0.254

Sources: 1. Royal Forest Department (1999).
2. TEI (1997).

Table D.4.1 Calculation of CO_2 emission from forest by changes in forest and other woody biomass stocks in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY					
SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS					
WORKSHEET	ANNUAL BIOMASS C REMOVE					
SHEET	2 OF 3					
	STEP 2					
Harvest Categories (specify)	F Commercial Harvest (if applicable) (1000 m^3 round wood)	G Biomass [1] Conversion (t-dm/m^3)	H Total Biomass Removed in Commercial Harvest (kt-dm)	I Total Traditional Fuel Wood Consumed (kt-dm)	J Total Biomass Consumption (kt-dm)	K Total Biomass Consumption From Stocks (kt-dm)
			H = (F×G)		J = (H+I)	K = J
Default values		0.5				
Round wood	34.9	0.5	17.45			
Fuel wood	32260	0.5		16130.00		
Total					16147.45	16147.45

Source: IPCC (1996b).

Table D.4.1 Calculation of CO_2 emission from forest by changes in forest and other woody biomass stocks in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY		
SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS		
WORKSHEET	NET CO_2 FLUX FROM PLANTATION FOREST OR MANAGED FOREST		
SHEET	3 OF 3		
STEP 3			
L Carbon Fraction [1]	M Annual Carbon Release, C_r (kt-C)	N Net Annual Carbon Uptake (+) or Release (-) (kt-C)	O Convert to CO_2 Annual Emission (-) or Removal (+), C_n (Gg-CO_2)
	M = (K×L)	N = (E-M)	O = (N×(44/12))
Default value = 0.5			
0.5	8073.73	-7920.10	-29040.37

Source: IPCC (1996b).

Table D.4.2 Calculation of CO_2 emission from forest by forest conversion in 1995.

MODULE	LAND USE CHANGE AND FORESTRY				
SUBMODULE	FOREST CONVERSION				
WORKSHEET	C RELEASED FROM BURNING OF ABOVE GROUND BIOMASS				
SHEET	1 OF 5				
	STEP 1				
Land types	A Area Converted [1] Annually (kha), A_f	B Biomass Before (t-dm/ha), BB_f	C Biomass After [2] Conversion (t-dm/ha), BA_f	D Net Change in Biomass Density (t-dm/ha)	E Annual Loss of Biomass (kt-dm)
				D = (B-C)	E = (A×D)
Default value			10		
EGF	34.75	337 [2]	10	327	11363.25
MDF	29.32	266 [3]	10	256	7505.92
DDF	17.84	126 [4]	10	116	2069.44
PF	1.09	160 [4]	10	150	163.50
MF	1.11	200 [5]	10	190	210.90
Other	2.23	217 [6]	10	207	461.61

Sources: 1. Royal Forest Department (1999).
2. TEI (1997).
3. Ogawa et al (1965).
4. Sahunalu P. and M. Jamroenpruksa (1980).
5. Aksornkaew et al (1987).
6. IPCC (1996b).

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Table D.4.2 Calculation of CO_2 emission from forest by forest conversion in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY					
SUBMODULE	FOREST CONVERSION					
WORKSHEET	C RELEASED FROM BURNING OF ABOVE GROUND BIOMASS					
SHEET	2 OF 5					
	STEP 2					
Land types	F Fraction of Biomass [1] Burned On Site, FBn_f	G Quantity of Biomass Burned On Site (kt-dm)	H Fraction of Biomass Oxidised On Site, FOn_f	I Quantity of Biomass Oxidised On Site (kt-dm)	J Carbon Fraction of Aboveground Biomass (burned on site), C_f	K Quantity of Carbon Released (from Burning biomass on site (kt-C), C_{bn}
		G = (E×F)		I = (G×H)		K = (I×J)
Default value			0.9		0.50 [1]	
EGF	0.07	795.43	0.9	715.88	0.54 [2]	386.58
MDF	0.08	600.47	0.9	540.43	0.52 [1]	281.02
DDF	0.07	144.86	0.9	130.37	0.49 [1]	63.88
PF	0.09	14.72	0.9	13.24	0.48 [3]	6.36
MF	0.00	0.00	0.9	0.00	0.55 [4]	0.00
Other	0.08	36.93	0.9	33.24	0.50	16.62
						754.46

Sources: 1. TEI (1997).
2. Xu (1992).
3. Tsutsumi et al (1983).
4. Aksornkaew. (1989).

Table D.4.2 Calculation of CO_2 emission from forest by forest conversion in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY							
SUBMODULE	FOREST CONVERSION							
WORKSHEET	C RELEASED FROM BURNING OF ABOVE GROUND BIOMASS							
SHEET	3 OF 5							
	STEP 3						STEP 4	
Land types	L Fraction of Biomass Decayed Off Site (Timber), FBf_f	M Quantity of Biomass Decayed Off Site (Timber) (kt-dm)	N Fraction of Biomass Decayed Off Site, FOf_f	O Quantity of Biomass Decayed Off Site (kt-dm)	P Carbon Fraction of Aboveground Biomass, C_f	Q Quantity of Carbon Released (from biomass decayed off site) (kt-C), C_{bf}	R Total Carbon Released (from on Site burning and off Site decaying (kt-C), C_{ab}	S Total CO_2 Released (from on site burning and off Site decaying (kt-CO_2)
		M = (E×L)		O = (M×N)		Q = (O×P)	R = (K+Q)	S = (R×(44/12))
Default value					0.50			
EGF	0.68 [1]	7727.01	1	7727.01	0.54	4172.59	4559.16	16716.93
MDF	0.66 [2]	4953.91	1	4953.91	0.52	2576.03	2856.05	10475.86
DDF	0.70 [3]	1448.61	1	1448.61	0.49	709.82	773.70	2836.91
PF	0.64 [4]	104.64	1	104.64	0.48	50.23	56.58	207.47
MF	0.81 [5]	170.83	1	170.83	0.55	93.96	93.96	344.51
Other	0.70	323.13	1	323.13	0.50	161.56	178.18	653.33
						7764.18		

Sources: 1. Ogawa et al (1965).
2. Sangtongpraw S. and S. Sukwong (1981).
3. Sahunalu P. and M. Jameronpruksa (1980).
4. Sahunalu et al (1981).
5. Aksornkaew (1989).

Table D.4.2 Calculation of CO_2 emission from forest by forest conversion in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY								
SUBMODULE	FOREST CONVERSION								
WORKSHEET	C RELEASED BY DECOMPOSITION OF ABOVE GROUND BIOMASS								
SHEET	4 OF 5								
	STEP 5								
Land types	A Average Converted in 1995 (kha), A_f (kha)	B Biomass Before Converion, BB_f (t-dm/ha)	C Biomass After Conversion, BA_f (t-dm/ha)	D Net Change in Biomass Density (t-dm/ha)	E Average Converted Biomass (kt-dm)	F Fraction Left to Decay (On-Site), FD_f	G Quantity of Biomass Left to Decay (On-Site) (kt-dm)	H Carbon Fraction In Aboveground, C_f	I C Released from Decay of Aboveground Biomass (all biomass left to decay on site) (kt-C), C_{agb}
				D = (B-C)	E = (A×D)		G = (E×F)		I = (G×H)
Default value								0.50	
EGF	34.75	337	10	327	11363.25	0.07	795.43	0.54	429.53
MDF	29.32	266	10	256	7505.92	0.07	525.41	0.52	273.22
DDF	17.84	126	10	116	2069.44	0.06	124.17	0.49	60.84
PF	1.09	160	10	150	163.50	0.08	13.08	0.48	6.28
MF	1.11	200	10	190	210.90	0.09	18.98	0.55	10.44
Other	2.23	217	10	207	461.61	0.09	41.54	0.50	20.77
									801.08

Table D.4.2 Calculation of CO_2 emission from forest by forest conversion in 1995 (cont.).

MODULE	LAND USE CHANGE AND FORESTRY			
SUBMODULE	FOREST CONVERSION			
WORKSHEET	TOTAL CO_2 RELEASED FROM FOREST CONVERSION			
SHEET	5 OF 5			
STEP 6				
A Immediate Release from On-site Burning (kt-C)	B Immediate Emissions from Decay Biomass on site (kt-C)	C Immediate Emission from Decay Biomass (Timber) Off-site (kt-C)	D Total Annual Carbon Release (kt-C)	E Total Annual CO_2 Release, FC (kt-CO_2)
			D = (A+B+C)	E = (D×(44/12))
754.46	801.08	7764.18	9319.72	34172.30

Table D.4.3 Calculation of CH_4 and N_2O emission from forest by forest conversion in 1995.

MODULE	LAND USE CHANGE AND FORESTRY
SUBMODULE	FOREST CONVERSION
WORKSHEET	CH_4 AND N_2O EMISSION FROM ON-SITE BURNING
SHEET	1 OF 1

STEP 1			STEP 2				
A Quantity of Carbon Released (kt-C)	B Nitrogen-Carbon Ratio	C Total Nitrogen Released (kt-N)		D Trace gas emissions Ratio	E Trace gas Emissions (kt-C)	F Conversion Ratio	G Trace Gas Emissions From burning of Cleared Forests (Gg CH_4,N_2O)
	Default value 0.01	C = (A×B)			E = (A×D)		G = (E×F)
754.46	0.01	7.54	CH_4	0.012	9.05	16/12	12.07
					(kt-N)		
					E = (C×D)		
			N_2O	0.007	0.05	44/28	0.1

Table D.4.4 Calculation of CO_2 emission from forest by abandonment of managed land in 1995.

MODULE	LAND USE CHANGE AND FORESTRY					
SUBMODULE	ABANDONMENT OF MANAGED LAND					
WORKSHEET	ANNUAL C UPTAKE IN ABOVE GROUND BIOMASS					
SHEET						
	STEP 1					STEP 2
Regrowth Land Type	A Present Area Abandoned and Regrowing (kha), AY	B Annual Rate of Aboveground Biomass Growth (t-dm/ha), RB	C Annual Aboveground Biomass Growth (kt-dm)	D Carbon Fraction of Aboveground Biomass, C	E Annual Carbon Uptake in Aboveground Biomass (kt-C), C_{BR}	F Total Carbon Dioxide Uptake (Gg-CO_2)
			C = (AxB)		E = (CxD)	F = (Ex[44/12])
EGF	1532.91	84/20	6438.22	0.54	3476.64	12747.67956
MGF	1293.36	67/20	4332.76	0.52	2253.03	8261.12144
DDF	786.83	32/20	1258.93	0.49	616.87	2261.873973
PF	47.99	40/20	95.98	0.48	46.07	168.9248
MF	49.13	50/20	122.83	0.55	67.55	247.6970833
Other	98.26	55/20	270.22	0.52	139.43	511.24678
Total	3808.48				6599.60	24198.54364

Source: 1. Royal Forest Department (1993).

5. Waste

Table D.5.1 Calculation of CH_4 emission from solid waste by landfill in 1995.

MODULE		WASTE							
SUBMODULE		SOLID WASTE							
WORKSHEET		CH_4 EMISSIONS FROM LANDFILL							
SHEET									
	STEP 1	STEP 2				STEP 3			
	A Annual [1] MSW Landfilled (Gg)	B Fraction [2] DOC	C Annual DOC Landfilled	D Annual [3] Which Actually Degrades	E Annual Carbon Released as Biogas (Gg)	F Fraction C-CH_4 To C-Biogas	G Annual Carbon Release as CH_4 (Gg-C)	H Conversion Ratio (16/12)	I CH_4 Emissions (Gg-CH_4)
			$C = A \times B$		$E = C \times D$		$G = E \times F$		$I = G \times H$
Metropolitan	1880.882	0.1337	251.47	0.77	193.63	0.55	106.50	1.33	141.64
Non-metropolitan (municipal and sanitary)	672.435	0.1436	96.56	0.77	74.35	0.55	40.89	1.33	54.39
Total									196.03

Source: 1. Office of Environment at Policy and Planning (2000).
2. TEI (1997).
3. IPCC (1996a).

Table D.5.2 Calculation of CH_4 emission from solid waste by opendumping in 1995.

MODULE	WASTE								
SUBMODULE	SOLID WASTE								
WORKSHEET	CH_4 EMISSIONS FROM OPENDUMPING								
SHEET									
	STEP 1	STEP 2				STEP 3			
	A Annual [1] MSW Opendump (Gg)	B Fraction [2] DOC	C Annual DOC Opendump	D Annual Which Actually Degrades	E Annual Carbon Released as Biogas (Gg)	F Fraction C-CH_4 To C-Biogas	G Annual Carbon Release as CH_4 (Gg-C)	H Conversion Ratio (16/12)	I CH_4 Emissions (Gg-CH_4)
			$C = A \times B$		$E = C \times D$		$G = E \times F$		$I = G \times H$
Metropolitan	302.354	0.1436	43.42	0.77	33.43	0.275	9.19	1.33	12.23

Source: 1. Office of Environment at Policy and Planning (2000).
2. TEI (1997).

Table D.5.3 Calculation of CH_4 emission from wastewater by industrial wastewater in 1995.

MODULE	WASTE				
SUBMODULE	WASTEWATER				
WORKSHEET	CH_4 EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT				
SHEET					
	STEP 1			STEP 2	
	A Production[1] (tonne/yr)	B Influent BOD[1] loading (kg/t-production)	C BOD generated (t-BOD)	D Methane[2] emission factor (Gg-CH_4/t-BOD)	E Methane emission (Gg-CH_4)
			$C = (AxB)x10^{-3}$		E = (CxD)
Slaughterhouse	432890.00	90.53	39.19	0.22	8.62
Milk	3311155.90	3.5	11.59	0.22	2.55
Fat & Oil	4373656.30	9.6	41.99	0.22	9.24
Fruit & Vegetable	6801921.00	15.73	106.99	0.22	23.54
Starch	4893949.20	170.15	832.71	0.22	183.20
Starch Food	2376788.75	125.31	297.84	0.22	65.52
Sugar	28837883.50	1.39	40.08	0.22	8.82
Ice Cream	183204.45	46.81	8.56	0.22	1.89
Feedstock	13453586.10	0.8	10.76	0.22	2.37
Distillation	2649188.25	29.46	78.05	0.22	17.17
Non-alcoholic Beverage	10141780.50	8.22	83.37	0.22	18.34
Pulp & Paper	1087506.55	24.41	26.55	0.22	5.84
Cold Storage	17058607.15	9.06	154.55	0.22	34.00

Source: 1. CMS Environmental Consultant (1997).
2. IPCC (1996a).

Table D.5.4 Calculation of CH_4 emission from wastewater by domestic wastewater treatment in 1995.

MODULE	WASTE						
SUBMODULE	WASTEWATER						
WORKSHEET	CH_4 EMISSIONS FROM DOMESTIC WASTEWATER TREATMENT						
SHEET							
	STEP 1			STEP 2			
	A	B	C	D	E	F	G
	Population[1] 1000 persons	Wastewater[2,3] BOD Value (Gg BOD/ 1000 persons/ year	Annual BOD (Gg BOD)	Fraction[4] Wastewater Anaerobically Treated	Quantity of BOD from Anaerobically Treated wastewater (Gg-BOD)	Methane[4] Emissions Factor (Gg-CH_4/ Gg-BOD)	Methane Emissions ($Gg-CH_4$)
			C = (AxB)		E = (CxD)		G = (ExF)
Metropolitan	5570.743	0.013055	72.723	0.1	7.272	0.22	1.600
Non-Metropolitan	59450.375	0.005256	312.524	0.1	31.252	0.22	6.876
Total							8.476

Source: 1. National Statistical Office (2000).
2. Metropolitan Waterworks Authority (2000).
3. Provincial Waterworks Authority (1998).
4. IPCC (1996a).

APPENDIX E

Basic Data

Table E.1 Energy consumption by sector in 1990 (TJ).

Fuel Type	Power	Agriculture	Residential & Commercial	Industrial, mining & Construction	Transportation	Total
Fossil	**386284.54**	**75865.21**	**38832.17**	**163931.25**	**480246.63**	**1145159.80**
Liquid	**106703.59**	**75865.21**	**38832.17**	**118904.64**	**480244.63**	**820550.24**
Gasoline		2172.12		787.00	113076.16	116035.28
Jet Kerosene					81559.86	81559.86
Kerosene		34.53	2209.92	2037.27		4281.72
Diesel Oil	6045.72	73313.46	36.42	16898.88	261022.14	357316.62
Fuel Oil	100657.87	238.62	835.17	90476.75	19129.37	211337.78
LPG		106.48	35750.66	8704.74	5457.10	50018.98
Solid	**103391.25**			**33880.05**		**137271.30**
Anthracite				188.40		188.40
Coking Coal				2016.99		2016.99
Briquette & other Coal				4641.12		4641.12
Lignite	103391.25			27033.54		130424.79
Gas	**176189.70**			**11146.56**	**2.00**	**187338.26**
Natural Gas	176189.70			11146.56	2.00	187338.26
Total Biomass			**183294.72**	**121712.19**		**305006.91**
Wood			89927.76	26047.71		115975.47
Charcoal			82221.36			82221.36
Paddy Husk			11145.60	23256.00		34401.60
Bagasse				72408.48		72408.48
Total	**386284.54**	**75865.21**	**222126.89**	**285643.44**	**480246.63**	**1450166.71**

Table E.2 Energy consumption by sector in 1995 (TJ).

Fuel Type	Power	Agriculture	Residential & Commercial	Industrial, mining & Construction	Transportation	Total
Fossil	**692422.26**	**66131.54**	**61006.70**	**346085.18**	**792720.83**	**1958366.51**
Liquid	**237068.25**	**66131.54**	**61006.70**	**197598.68**	**792581.09**	**1354386.26**
Gasoline		2046.20		2864.68	193192.76	198103.64
Jet Kerosene					109563.69	109563.69
Kerosene		34.53	1519.32	1968.21		3522.06
Diesel Oil	27679.20	63188.70	254.94	27315.00	449896.26	568334.10
Fuel Oil	209389.05	755.63	5885.96	153631.51	33486.34	403148.49
LPG		106.48	53346.48	11819.28	6442.04	71714.28
Solid	**142456.77**			**115435.44**		**257892.21**
Anthracite				376.80		376.80
Coking Coal				2763.00		2763.00
Briquette & other Coal	263.70			60835.59		61099.29
Lignite	142193.07			51460.05		193653.12
Gas	**312897.24**			**33051.06**	**139.74**	**346088.04**
Natural Gas	312897.24			33051.06	139.74	346088.04
Total Biomass	**12732.81**		**322634.14**	**176179.89**		**511546.84**
Wood	287.82		128719.50	31228.47		160235.79
Charcoal			193871.44			193871.44
Paddy Husk	374.40		43.20	24667.20		25084.80
Bagasse	12070.59			120284.22		132354.81
Total	**705155.07**	**66131.54**	**383640.84**	**522265.07**	**792720.83**	**2469913.35**

Table E.3 Energy consumption by sector in 1998 (TJ).

Fuel Type	Power	Agriculture	Residential & Commercial	Industrial, mining & Construction	Transportation	Total
Fossil	**821592.51**	**78655.91**	**58323.69**	**308163.85**	**796474.95**	**2063210.91**
Liquid	**181654.83**	**78655.91**	**58323.69**	**175335.17**	**796462.08**	**1290431.68**
Gasoline		2109.16		2203.60	221335.88	225648.64
Jet Kerosene					114432.42	114432.42
Kerosene		34.53	725.13	1139.49		1899.15
Diesel Oil	11399.46	76299.90	182.10	34016.28	435328.26	557226.00
Fuel Oil	170255.37	159.08	715.86	124639.18	20680.40	316449.89
LPG		53.24	56700.60	13336.62	4685.12	74775.58
Solid	**162913.26**			**95841.44**		**258754.70**
Anthracite				973.40		973.40
Coking Coal				2210.40		2210.40
Briquette & other Coal	1423.98			38684.79		40108.77
Lignite	161489.28			53972.85		215462.13
Gas	**477024.42**			**36987.24**	**12.87**	**514024.53**
Natural Gas	477024.42			36987.24	12.87	514024.53
Total Biomass	**8696.01**		**197049.30**	**160247.55**		**365992.86**
Wood	671.58		99873.54	34794.24		135339.36
Charcoal			95217.36			95217.36
Paddy Husk	2520.00		1958.40	30974.40		35452.80
Bagasse	5504.43			94478.91		99983.34
Total	**830288.52**	**78655.91**	**255372.99**	**468411.40**	**796474.95**	**2429203.77**

Table E.4 Production of industry in Thailand in 1990-2000.

Industry	Amount Produced										
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cement tonnes	18059000	19165000	21723000	26300000	29929000	34051000	38749000	37115000	22722000	25354000	25484000
Glass tonnes	218600		316880	379406	403767	463122	436045		377913	463576	511265
Lime tonnes	91616	108052	121044	129897	145615	154595	160443	167884	124439	121120	107694
Paper Pulp tonnes	154558	166019	181119	180625	236805	299862	506706	572700	696862	853559	914859
Iron and Steel (Steel bar & Shape Steel) tonnes	827439	870245	974536	1134778	1488467	1974162	2076860	2107528	1395719	1227472	1350200
Bakery tonnes	1859350.2	1980917.1	2125862.2	2287951.4	2316005.3	2376788.8	2429779.5	2489004.4	2527968.1	2527968.1	2560697.65
Beer thousand litres	263483	284048	325202	415311	523028	647309	759072	874231	976983	1042221	1165367
Wine thousand litres	296241.3	296241.3	296241.3	296241.3	493735.5	493735.5	493735.5	592482.6	592482.6	592482.6	592482.6
Whisky thousand litres	624000	596180	603820	699660	695600	844920	800840	916260	915140	1345340	614460
Soft drink thousand litres	1117206	1196022	1279887	1349069	1552748	1645693	1757030	1742926	1547440	1384484	1381000

Table E.5 Number of dairy cow in Thailand (head).

Year	Dairy Cow	Dairy Female		Heifer	Total	Raw Milks
		0-1yr	1-2 yr	> 2		(kg/day)
1990	74965	24272	23931	34369	157537	
1991	105145	26660	25360	34029	191194	633508
1992	121279	29599	26972	44649	222499	719120
1993	121191	31204	35766	49028	237189	930241
1994	120347	30291	31145	49835	231618	969676
1995	167187	38502	41900	39658	287247	1224224
1996	120348	51170	61800	42394	275712	1411822
1997	127491	49647	67355	43747	288240	1371940
1998	142752				295345	1304437
1999	115394	55679	67038	35816	273927	1097852

Table E.6 Number of livestock in Thailand (head).

Year	Non-dairy cattle	Buffalo	Goat	Sheep	Swine	Horse	Poultry
1990	5510993	4694290	120519	162496	7349710	19758	125979828
1991	6435777	4805071	136035	166102	8202472	20331	150496763
1992	6898980	4728271	159642	176229	8332668	18852	154960116
1993	7235384	4804146	151860	110465	8569126	18047	161158561
1994	7405732	4224791	141076	90508	8479400	14032	152269312
1995	7321821	3710061	132400	75329	8561921	16875	130958286
1996	5854529	2711737	118829	40900	8707887	12003	165979803
1997	5291936	2293938	125262	41926	10139040	14672	186691559
1998	4567950	1951068	130904	40404	8772275	11322	175280520
1999	4635741	1799606	132845	39485	7423101	7350	192228634

Table E.7 Harvesting areas (ha) of both major and second rice, by water regime.

Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Major rice										
Irrigated	1882580.48	1977962.40	2169714.4	2066886.08	2153939.68	1943088.96	2049102.24	2080051.52		
Rainfed	6211743.2	6214094.88	6167064	5901775.84	6097944.96	6163905.60	6094411.04	6608879.84		
Deep water	39255.20	104058.40	93554.40	24030.72	36015.20	2616.96	22340.16	45451.84		
Dry	74955.36	56160.16	81549.60	7698.08	7206.40	44308.64	86380.80	45455.36		
Sub-total	8208534.24	8352275.84	8511882.40	8000390.72	8295106.24	8153920.16	8252234.24	8779838.56		
Second rice										
Irrigated	730784.16	583350.56	700670.88	647856.64	482041.44	680122.88	945240.32	1014909.76	1132951.36	1018680.80
Total Area	8939318.40	8935626.40	9212553.28	8648247.36	8777147.68	8834043.04	9197474.56	9794748.32		

Table E.8 Harvested area and production (1000 ha)

Year	Rice				Major rice	Second rice
	North	Northeast	Middle	South		
1990	1952.12	4781.67	1746.57	458.95	8208.48	730.72
1991	1895.02	4590.41	1969.25	480.96	8352.32	583.36
1992	2010.10	4832.22	1909.44	460.79	8511.84	700.64
1993	1849.59	4430.88	1923.14	444.64	8000.32	647.84
1994	1879.28	4581.32	1867.55	449.00	8295.04	482.08
1995	1770.36	4820.77	1802.61	454.09	8167.68	680.16
1996	2068.14	4609.71	2054.27	465.35	8252.32	945.28
1997	2266.67	5000.46	2085.88	441.73	8779.84	1014.88
1998	2367.91	4714.63	2040.98	450.79	8492.8	1132.96
1999						1018.72

Table E.8 Harvested area and production (1000 ha) (cont.).

Year	Maize	Sorghum	Cassava	Sugar cane	Mungbean	Soybean	Groundnut
1990	1545.12	188.32	1487.52	782.56	427.84	407.84	117.44
1991	1398.56	192.48	1433.6	916.64	417.6	318.24	109.92
1992	1236	173.12	1450.56	991.68	350.24	343.2	100.48
1993	1217.6	146.08	1438.08	799.52	314.56	379.84	91.52
1994	1351.36	167.2	1382.72	922.72	335.04	395.36	100.16
1995	1263.36	128.96	1245.12	984.96	332.8	275.04	96.8
1996	1314.72	134.24	1228.16	980.32	303.36	255.52	95.36
1997	1198.08	104.32	1230.4	980.32	273.44	236	81.76
1998	1380.48	97.44	1044.32	980.32	288.8	219.2	86.56
1999			1065.44				

Table E.9 Chemical nitrogen fertilizer consumption by crop type in 1990.

Crop Type	Fertilizer Grade							
	21-0-0	46-0-0	16-20-0	16-16-16	15-15-15	13-13-21	Others	Total
Fertilizer consumption:	1000 tonnes fertilizer							
Rice	173.038	261.804	348.890	132.906	0.000	0.000	74.692	991.330
Upland crops	114.770	34.531	119.756	14.616	131.307	47.086	89.904	551.970
Fruit tree	18.761	44.710	0.000	0.000	218.267	30.392	384.055	696.185
Vegetables & Ornamental	98.877	86.311	84.582	0.000	56.305	36.079	47.269	409.423
Total	405.446	427.356	553.228	147.522	405.879	113.557	595.920	2648.908
Nitrogen content:	1000 tonnes N							
Rice	36.338	120.430	55.822	21.265	0.000	0.000	7.469	241.324
Upland crops	24.102	15.884	19.161	2.339	19.696	6.121	8.990	96.293
Fruit tree	3.940	20.567	0.000	0.000	32.740	3.951	38.406	99.603
Vegetables & Ornamental	20.764	39.703	13.533	0.000	8.446	4.690	4.727	91.863
Total	85.144	196.584	88.516	23.604	60.882	14.762	59.592	529.084

Table E.10 Chemical nitrogen fertilizer consumption by crop type in 1995.

Crop Type	Fertilizer Grade							
	21-0-0	46-0-0	16-20-0	16-16-16	15-15-15	13-13-21	Others	Total
Fertilizer consumption:	1000 tonnes fertilizer							
Rice	139.120	334.775	495.102	328.555	0.000	0.000	204.344	1501.896
Upland crops	61.517	30.446	62.969	20.729	165.145	36.040	204.356	581.202
Fruit tree	11.553	35.114	0.000	0.000	215.656	26.160	484.900	773.383
Vegetables & Ornamental	58.671	66.321	49.971	0.000	79.882	28.965	173.022	456.832
Total	270.861	466.656	608.042	349.284	460.683	91.165	1066.622	3313.313
Nitrogen content:	1000 tonnes N							
Rice	29.215	153.997	79.216	52.569	0.000	0.000	20.434	335.431
Upland crops	12.919	14.005	10.075	3.317	24.772	4.685	20.436	90.208
Fruit tree	2.426	16.152	0.000	0.000	32.348	3.401	48.490	102.818
Vegetables & Ornamental	12.321	30.508	7.995	0.000	11.982	3.765	17.302	83.874
Total	56.881	214.662	97.287	55.885	69.102	11.851	106.662	612.331

Table E.11 Chemical nitrogen fertilizer consumption by crop type in 1998.

Crop Type	Fertilizer Grade							
	21-0-0	46-0-0	16-20-0	16-16-16	15-15-15	13-13-21	Others	Total
Fertilizer consumption:	1000 tonnes fertilizer							
Rice	177.882	428.052	633.050	420.099	0.000	0.000	261.279	1920.362
Upland crops	48.656	24.081	49.805	16.395	130.620	28.506	161.634	459.697
Fruit tree	9.135	27.764	0.000	0.000	170.515	20.684	384.401	612.499
Vegetables & Ornamental	46.348	52.392	39.476	0.000	63.105	22.882	136.682	360.885
Total	282.021	532.289	722.331	436.494	364.240	72.072	943.996	3353.443
Nitrogen content:	1000 tonnes N							
Rice	37.355	196.904	101.288	67.216	0.000	0.000	26.128	428.891
Upland crops	10.218	11.077	7.969	2.623	19.593	3.706	16.163	71.349
Fruit tree	1.918	12.771	0.000	0.000	25.577	2.689	38.440	81.396
Vegetables & Ornamental	9.733	24.100	6.316	0.000	9.466	2.975	13.668	66.258
Total	59.224	244.853	115.573	69.839	54.636	9.369	94.400	647.894

Table E.12 Estimated forest area by forest type in Thailand in 1988-2000.

Forest types	Estimated forest area (k-ha)												
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Tropical evergreen	5786.84	5771.10	5634.26	5502.10	5431.77	5375.53	5333.90	5292.28	5264.40	5236.53	5221.32	5204.98	5188.63
Mixed deciduous	4883.73	4870.44	4753.78	4642.27	4582.93	4535.48	4500.36	4465.23	4441.71	4418.20	4405.37	4391.58	4377.78
Dry dipterocarp	2971.08	2963.00	2892.02	2824.18	2788.08	2759.22	2737.85	2716.48	2702.17	2687.87	2680.06	2671.67	2663.28
Pine	181.20	180.71	176.38	172.24	170.04	168.28	166.97	165.67	164.80	163.93	163.45	162.94	162.43
Mangrove	185.51	185.01	180.58	176.34	174.09	172.28	170.95	169.62	168.72	167.83	167.34	166.82	166.29
Others	371.03	370.02	361.15	352.68	348.17	344.57	341.90	339.23	337.44	335.66	334.68	333.64	332.59
Total	14379.38	14340.27	13998.17	13669.81	13495.07	13355.35	13251.93	13148.51	13079.26	13010.00	12972.23	12931.62	12891.00

Table E.13 Estimated abandoned forest area by forest type in Thailand 1990-1998.

Forest types	Estimated forest area (k-ha)								
	1990	1991	1992	1993	1994	1995	1996	1997	1998
Tropical evergreen	1610.00	1596.48	1583.79	1569.62	1556.74	1532.91	1500.97	1461.17	1419.70
Mixed deciduous	1358.40	1346.99	1336.29	1324.33	1313.46	1293.36	1266.41	1232.83	1197.84
Dry dipterocarp	826.40	819.46	812.95	805.67	799.06	786.83	770.44	750.01	728.72
Pine	50.40	49.98	49.58	49.14	48.73	47.99	46.99	45.74	44.44
Mangrove	51.60	51.17	50.76	50.31	49.89	49.13	48.11	46.83	45.50
Others	103.20	102.33	101.52	100.61	99.79	98.26	96.21	93.66	91.00
Total	4000.00	3966.40	3934.88	3899.68	3867.68	3808.48	3729.12	3630.24	3527.20

Table E.14 Waste disposal, by methods (tonne/year), Bangkok metropolitan region.

	Year		
	1990	1995	1998
Open Dumping	1321778	302354	0
Sanitary Landfills	566476	1880882	3071475
Composing		365331	non-operate

Table E.15 Waste disposal, by methods (tonne/year), Non-metropolitan (municipal and sanitary).

	Year		
	1990	1995	1998
Sanitary Landfills	435149	672435	656885

Table E.16 Number of factories in Thailand in 1990-1999.

Type of Industry	Number of Factories									
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
4 (1)	51	55	65	73	95	100	104	110	121	126
5 (1)	15	16	20	27	37	44	47	61	62	66
5 (3)	7	7	7	7	7	7	8	9	9	9
5 (5)	3	3	5	5	5	5	5	5	5	5
5 (6)	18	18	18	18	18	18	18	20	20	20
Total	43	44	50	57	67	74	78	95	96	100
7 (1)	179	185	194	202	209	213	215	235	247	259
7 (4)	8	8	8	8	8	8	8	11	11	12
Total	187	193	202	210	217	221	223	246	258	271
8 (1)	191	219	245	266	292	315	326	333	341	351
9 (2)	142	156	162	170	177	184	188	192	195	200
10 (1)	293	314	341	359	380	388	400	421	440	451
10 (2)	128	144	153	160	166	171	172	178	181	183
10 (3)	772	813	870	913	940	966	987	998	1001	1009
Total	1193	1271	1364	1432	1486	1525	1559	1597	1622	1643
11 (2)	81	84	88	90	91	92	94	94	93	91
11 (3)	42	45	47	49	52	54	57	57	57	57
Total	123	129	135	139	143	146	151	151	150	148
12 (11)	230	256	271	278	288	297	308	306	307	311
15 (1)	141	171	189	204	226	246	266	272	275	281
15 (2)	240	267	289	310	324	333	354	354	351	349
Total	381	438	478	514	550	579	620	626	626	630
16	43	43	44	45	45	45	45	46	47	50
20 (1)	123	146	168	170	179	184	188	196	205	210
20 (2)	19	19	22	25	31	39	42	45	48	50
20 (3)	20	20	21	21	22	23	24	25	25	23
Total	162	185	211	216	232	246	254	266	278	283
38 (1)	4	4	7	8	9	13	15	14	16	17
92	272	295	325	354	372	403	422	461	485	501

APPENDIX F

Greenhouse Gas Mitigation Options

F. Greenhouse Gases Mitigation Options

This appendix is designed to provide a list of options for reducing greenhouse gases in Thailand. Mitigation options are presented for four sectors: Energy, Agriculture, Forest, and Waste.

F.1 Energy Sector

The energy sector has become the largest source of CO_2 emissions in Thailand, accounting for more than half of the country's total CO_2 emissions. In this study, Transport, Industry and Power were main sub-sectors of CO_2 emission. The mitigation options for reducing energy related GHGs emissions from this sector include:

1. Improvement of electricity generation and efficiency through the use of co-generation power which produces heat and power simultaneously, and the use of more efficient motors, electrical drive systems, lighting and industrial process modifications.
2. Improvement of fuel efficiency by improving energy management, waste heat recovery and boiler modifications.
3. Fuel switching from coal to natural gas or oil.
4. Incorporation of new process technology, i.e. increase recycling and reduce energy consumption through use of less energy intensive processes.
5. Shift of fuel use in the transportation sector, whereby the share of natural gas consumption is increased and introduction of higher fuel efficiency and reduced greenhouse gases emitting propulsion systems in road transport vehicles.
6. Encouragement of the deployment of energy-efficient and lower greenhouse gases emitting technologies in the market, especially technologies in the transport sector.
7. Encourage industry to opt for the use of energy-efficient design and devices in their new investments.

8. Encourage industry to undertake retrofits to existing plants to improve their energy efficiency.

F.2 Agriculture Sector

F.2.1 Livestock

Based on studies conducted in Thailand and abroad, the following options to reduce CH_4 emissions from enteric fermentation were identified (Vijchulata, 1997):

1. Use of mineral supplements to meet minimum nutrient requirements so that feed can be reduced.
2. Supplementation of poor quality roughage with a urea-molasses, legumes, and/or low-cost agricultural by-products.
3. Chemical treatment low-quality roughage, particularly with urea solution, in order to improve the digestibility and to increase the non-protein nitrogen content of fibrous feeds.
4. Expansion of pasture and forage conservation for dry season feeding, particularly in the case of dairy cattle.
5. Mitigation of methane production from rumen fermentation by using ionophore, particularly nonensic acid, in ruminants.

F.2.2 Rice Cultivation

There are two possible approaches to mitigate methane emissions from paddy fields (Jermsawatdipong, 1997): (1) using a rice production technology to prevent methane emissions, and (2) reducing methane emissions by changing rice cultivation practices. Few studies have been conducted on the mitigation of methane emissions from rice field, and as yet no model exists to assess the cost effectiveness of various options. The following list summarizes factors that are important in considering greenhouse gas mitigation options that may be applied to the situation in Thailand, base on studies from other country sources.

1. Water and soil management
    - Aerating the soil naturally or by drainage during midseason tilling or late tilling. This has been claimed to reduce methane emission significantly.
    - Controlling soil moisture during the drainage period can also reduce methane emissions.

2. Organic matter amendment
    - Minimizing the use of green manure and substituting pre-fermented compost from farm residues. A recent finding by the Natural Resource Management Program (NRM, 1998) suggests this prescription to reduce methane from rice production.

3. Inorganic fertilizer
    - Adding nitrate or sulfate-containing nitrogen fertilizer to suppress CH_4 production.
    - Surface application of fertilizer, particularly ammonium sulfate, to decrease CH_4 emissions. The effectiveness of this method has been recently confirmed by a recent study by TEI (NRM, 1998).

4. Rice cultivation
    - Minimize use of the tall, traditional rice variety, which has more tillers and intensive roots, characteristics that encourage greater emissions of CH_4.
    - Encourage use of high yielding rice varieties, with more productive tillers and a shorter seasonal cropping period, tending to emit lower amounts of CH_4.
    - Root exudates is an important source of CH_4 production.

5. Soil cultivation practice
    - Minimizing soil disturbance, plowing and puddling, transplanting of rice seedlings, and weeding and broadcasting fertilizer application decrease the rate of release of CH_4 entrapped in the soil.

- Planting by dry, direct seeding causes less soil disturbance and less CH_4 emissions than wet, direct seeding.

6. Methane product inhibitors
   - Chemicals which effectively inhibit CH_4 production are sulfate-containing compounds such as gypsum, sodium sulfate, and ammonium sulfate.
   - The slow release of acetylene from calcium carbide, encapsulated in fertilizer granules, greatly reduces CH_4 emissions.

F.3 Forest Sector

In the Land Use Change & Forestry sector existing mitigation options are: (1) increase efficiency of use and production (harvest), and (2) protection of existing forests and creation of new forest covers through reforestation and/ or afforestation. While the first option has been continuing in Thailand, only reforestation and afforestation are considered in this study (ALGAS, 1998).

Land areas are classified into two major categories: protected area systems (PAS) on which management is only for carbon sinks, and non-protected area systems (NPAS) on which multiple use is allowed. This NPAS can also be broken down to pure NPAS and community forest area (CMF). Modeling of least cost is done using the COMAP model, developed by Sathaye an Makudi of Lawrence Berkeley Laboratory (LBL) and Andrasko of US.EPA (LBL, 1995 and Sathaye et al., 1994), in addition to the baseline scenario, which assumes continuation of current practices. Mitigation options considered under the modified COMAP are:

1. Forest protection and reforestation for conservation in the protected area system according to the Thai Forest Master Plan (TFMP);
2. Forest protection and reforestation in the community forest areas (CMF);
3. Short rotation in CMF;
4. Short rotation in non-protected area system (NPAS);
5. Medium rotation in non-protected area system (NPAS); and
6. Long rotation in CMF.

The goal of Thailand's forestry policy is to achieve self-sufficiency by maintaining the existing 14.1 million hectares of protected forest area and reforesting an additional 0.8 million hectares. The forestry sector mitigation options identified for Thailand in the context of this goal are listed in Table F.1.

Table F.1 Greenhouse gas mitigation options for Thailand's forestry sector.

Option	Sequestration potential (tones of CO_2/ha)	Investment cost ($/ha)	Abatement cost ($/tonne of CO_2)
Forest protection and reforestation for conservation in protected areas	117	283.8	-27.13
Forest protection and reforestation for conservation in community forests	143	408.0	-27.87
Short rotation in community forests	680	544.6	-2.93
Long rotation in community forests	620	550.0	-11.73
Short rotation in non-protected area	583	466.7	-3.3
Medium rotation in non-protected area	416	489.0	5.13

Source: Asian Development Bank [ADB] (1998f).

F.4 Waste Sector

It is expected that this sector will grow significantly because of population increases and the growing volume of solid waste. Compared to emissions of methane from the rice sub-sector, however, emissions from the wastes sector will remain marginal. The most sensible strategy, therefore, is to improve management in such a way that wastes can be turned into profit for local communities.

Four options to reduce CH_4 emissions from landfill site were identified, namely:

- recycling
- control of waste generation rates
- control of waste generation rates combined with recycling and
- conversion of waste into energy.

Since 1995, the Thai Government has promoted electricity generation by private sector through the SPP and IPP production schemes. Electric generation plants utilizing CH_4 from landfills are potential SPP projects, and about 75 MW of potential electricity generating capacity have been identified (EGAT, 1999). To be viable, though, such projects require landfill sites to be sufficiently large and that solid waste management operations are implemented systematically. To reduce waste generation, the Bangkok Metropolitan Administration has promoted recycling and reuse of solid wastes strongly.

For wastewater treatment facilities, basically two strategies are available-aerobic and anaerobic treatment systems. The choice as to which system to develop depends on a number of factors, including wastewater characteristics and properties, waste volume, organic loading, budget, etc. If the anaerobic system is chosen, it should be equipped with energy recovery devices for heat or electricity generation. As with solid wastes, however, the viability of the project depends on the size of the methane recovery site.

Bibliography

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