The Preliminary Study on the Comparative Assessment of Carbon Stock Related to Changes in Land Use in Phuket and Phayao Provinces

EVA NOVITA SARI

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Earth System Science

Prince of Songkla University

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ABSTRACT

Recently, land use in Thailand has been significantly changed due to the dynamic from economic development. One of the consequence is the change of soil carbon stock. This study investigates the carbon stock change related to the change in land use in Phuket and Phayao due to the development of agriculture and tourism - two main economic sectors in Thailand from the years 2007 to 2009. Phuket is chosen as a representative of tourist provinces, while Phayao is chosen as a representative of agricultural provinces in Thailand. In order to determine land-use change in these two provinces, Geographic Information System (GIS) was employed, and to calculate the carbon stored in soil, Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines were applied. Land use in Phuket - a tourism destination was altered due to the tourism expansion. From 2007 to 2009, village and golf course areas grew by 48.1 km^2 (45.2%) and 3.6 km^2 (3.4%), respectively, while that of other urban (for example, factory and trading centers of agricultural product), other land (for example, mining and landfill), rubber, and evergreen forest areas dropped by 28.2 km^2 (26.5%), 11.1 km^2 (10.5%), 4.1 km^2 (3.8%) and 3.4 km^2 (3.2%), respectively. Because of the conversion from forest area (including evergreen forest, deciduous forest, and mangrove forest) and rubber plantation into settlements areas, the total carbon stock in Phuket felt by nearly 130,000 t C from 2007 to 2009. Differently, in Phayao, most of land-use change is due to the effect of agriculture. Between 2007 and 2009, the area of rubber plantation and other agricultural areas increased by approximately 50.5 km^2 (27.8%) and 34.5 km^2 (19.0%), respectively. While the area of corn plantation and deciduous forest declined by 46.66 km^2 (25.7%) and 28.5 km^2 (15.7%), respectively.

The deforestation was caused by the expansion of other crops' plantation area, while the maize plantation area was converted mostly into rubber plantation and longan. The decline in the area of forest including evergreen forest and deciduous forest was the main reason for a reduction of more than 500,000 t C in soil carbon stock in Phayao. Even though there were different trends in the change of land use in two provinces, both of them have undergone a decrease in soil carbon stock - the important matter that can change to be greenhouse gas emissions in atmosphere due to that decrease. Therefore, it is necessary to establish appropriate policy for land use planning and management in Phuket and Phayao to reduce loss of soil carbon stock in these provinces.

Keywords: Carbon stock, GHG emissions, Land use change, Phayao, Phuket, Tourism

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Eva Novita Sari

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

Figures **Page**

LIST OF TABLES

Tables **Page**

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CH_4	Methane
COP21	The 21st Session of the Conference of the Parties
CO_2	Carbon dioxide
CO_2*-eq*	Carbon dioxide equivalent
CSEF	Country Specific Emission Factor
EF	Emission factor
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information System
GPP	Gross Provincial Product
GWP	Global Warming Potential
INDCs	Intended Nationally Determined Contributions
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPCC	Intergovernmental Panel on Climate Change
LDD	Land Development Department
LULUCF	Energy, Industrial Processes, Agriculture, Land Use, and Land-Use Change and Forestry
MODIS	Moderate Resolution Imaging Spectroradiometer
MOE	Ministry of Energy
NTB	Nusa Tenggara Barat
N_2O	Nitrous oxide
N_2O	Nitrous oxide
RTG	The Royal Thai Government
SNC	Second National Communication
SOC	Soil organic carbon
TAT	Tourism Authority of Thailand
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Land use involves human activities that require the specific physical environment. The greatest influence of land use change is due to the pressure of rapid urbanization, and the change can cause several consequences (Hualong *et al*., 2014). Land use change directly affects terrestrial ecosystems. It is one of the main factors influencing biodiversity on a global scale (Sala *et al*., 2000). For example, these conditions can be indicated by land conversion from vegetated lands to non-vegetated lands or other vegetated lands. Such conversions especially deforestation has been historically recognized as a large source of the cumulative human-induced greenhouse gas (GHG) emissions, transformed from soil organic carbon (SOC) (Hualong *et al*., 2014; IPCC, 2007a).

GHG emissions are the main reason for an increase in the temperature on the Earth. In the last 100 years, the surface (global average) temperature had increased by 0.7 °C (IPCC, 2007a). This increase causes negative impacts not only on human life, but also on other species. Some important effects are insufficiency of food production, devastation of ecosystem, and decrease of economic development (IPCC, 2007b). Due to these reasons, development and adoption of global contribution so called, the Paris Agreement, with the target to limit the global average temperature rise to below 2°C above pre-industrial levels was announced. The Paris Agreement was adopted on 12 December 2015 at the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) and Thailand was one of the Parties. In alignment with its GHG emissions reduction policy, Thailand committed to reduce the emissions by 20–25% within 2030 (ONEP, 2015a). Therefore, Thailand needs to explore mitigation measures to achieve the emission reduction target.

Thailand has been one of the fastest-growing countries in Southeast Asia. Its gross domestic product (GDP) increased from 1,663 billion USD in 2012 to 1,730 billion USD in 2013 (NESDB, 2016). The increase in GDP growth rate in

Thailand can imply a high rate of land use conversion. Thai citizens usually experience the report regarding deforestation, one of the leading causes of global warming (15% of global GHG emissions). In Thailand, total forest area had been decreased from 54% (compared to the whole area) in 1961 to 32% in 2014 as a result of increase in population, development of structure and facilities, agricultural growth, legal and illegal logging, and wildfire. On average, the annual deforestation rate was estimated at 0.6% or 140,000 ha/year, from 1973 to 2014 (The World Bank, 2016). Apart from residential and factory areas, human activities that are considered as major drivers of land use conversion include tourism and agriculture (Terakunpisut, 2003).

Since tourism and agriculture are the essential sectors in economic growth in Thailand as well, their GHG emissions had been increased along with the activities related to the growth (Ramachandra *et al*., 2015). Consequently, in this study, Phuket province in Southern Thailand and Phayao province in Northern Thailand were selected for investigating characteristics and changes in land use and soil carbon stock, as these provinces are the representatives for tourist and agricultural provinces, respectively.

1.2 Research Objectives

The research objectives of this study are:

- To identify the change of land use in Phuket and Phayao provinces.
- To estimate carbon stock in soil according to the change in land use in these provinces.

1.3 Research Scope

The research scopes of this study are:

a) Method:

- Geographical Information System (GIS) was used in this study to identify land use and change.
- Intergovernmental Panel on Climate Change (IPCC) 2006 guideline was used in this study to estimate the carbon stock in soil.

b) Study area:

- The study areas are in Phuket and Phayao provinces – as a representative of tourist and agricultural provinces, respectively.

c) Time:

- Secondary data of land use for Phuket and Phayao provinces for years 2007 and 2009 obtained from the Land Development Department (LDD), a governmental organization, are applied.

CHAPTER 2
LITERATURE REVIEW

2.1 Greenhouse Gas Effect and Global Warming

As global warming increases intensely, its impacts are felt worldwide. There are several factors that can contribute to global warming, including natural changes and human activities. The major substances contributing to global warming threat are named GHG emissions – such as CO_2, CH_4, and N_2O (Casper, 2010). GHGs cause the global warming by absorbing the radiation within the earth (Al-Mahdi and Maina, 2013). For explanation about the cause of global warming in details, as shown in Figure 2.1, the incoming solar energy to the earth's surface is called solar radiation. The earth receives energy from the sun in the form of solar radiation absorbed by the earth's surface. As substances in the lower atmosphere, GHGs trap the outgoing infrared radiation. Therefore, the more GHG presents and accumulate in the atmosphere, the warmer the earth becomes (Latake *et al.*, 2015).

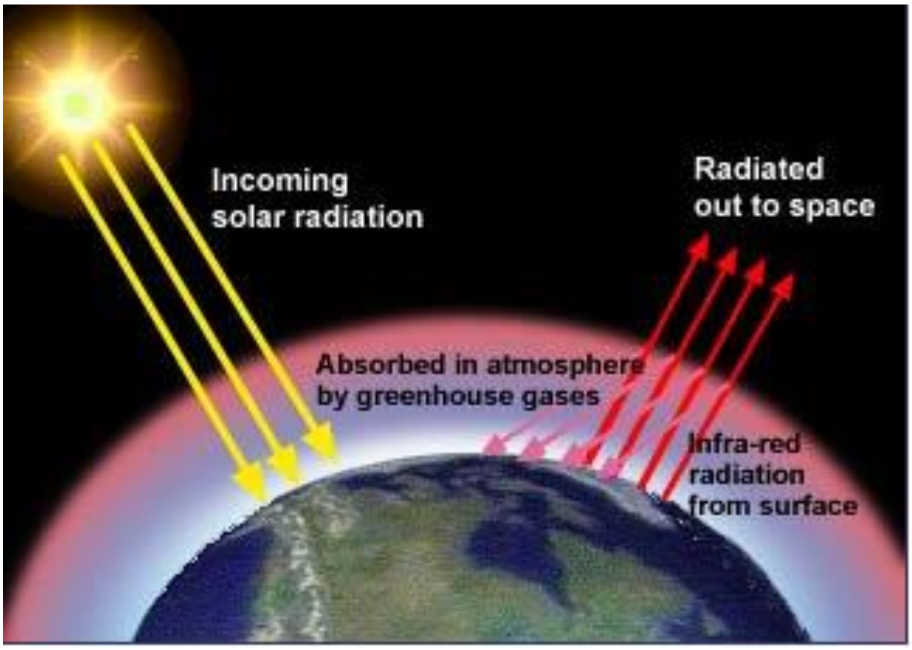

Figure 2.1 The GHG effect (Barry and Chorley, 2017)

In the last 100 years, the surface temperature by the global average had increased by 0.7 °C (IPCC, 2007a). Due to the negative predictable consequences, countries adopted the Paris Agreement to limit the global average temperature rise to below 2 °C relative to a pre-industrial baseline. As shown in Figure 2.2, in the 2 °C scenarios start from Intended Nationally Determined Contributions (INDCs) levels in 2030 (dark-orange range). The range of the scenario subset limits warming to below 2 °C in 2100 around 50%–66% probability (dark orange) from the year 2030 INDC levels. This probability is connected with a rapid decrease in CO_2 emissions from energy and industry related sources after 2030. Shortly, this goal is scientifically predicted that it is able to achieve sustainable development and prevent human-being from threat, known as global warming (Rogelj *et al.*, 2016).

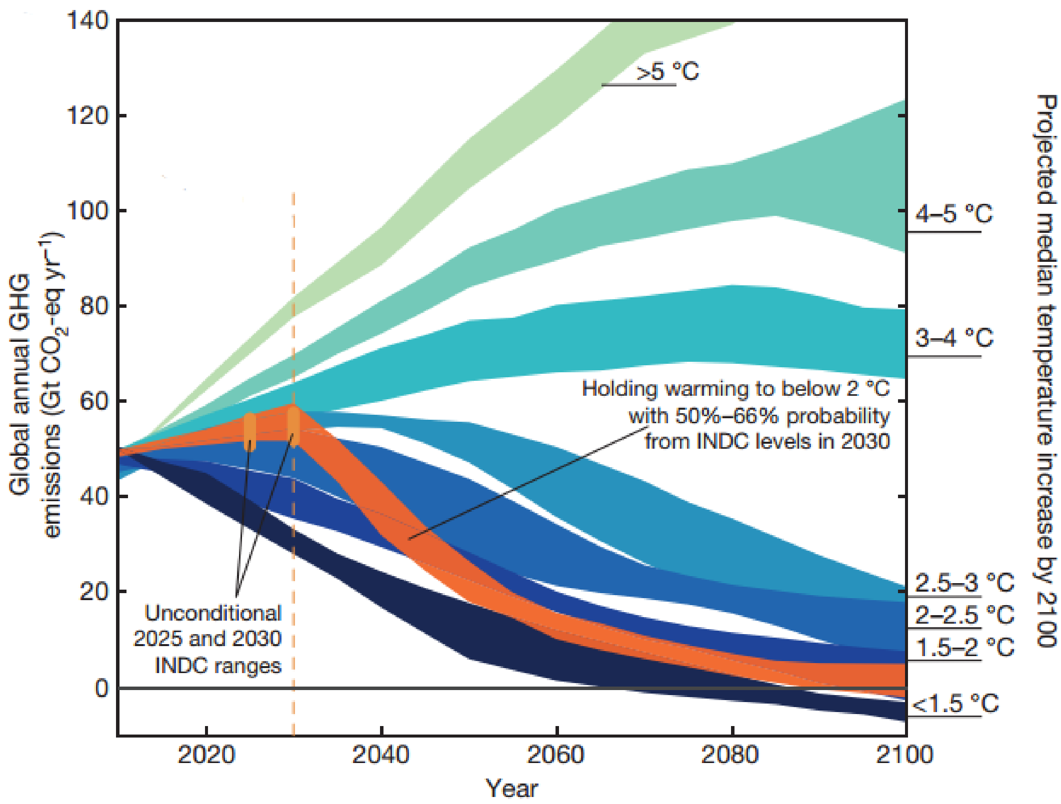

Figure 2.2 The global annual GHG and temperature (Rogelj *et al.*, 2016)

Back to the source of GHGs released to the atmosphere, they can be created naturally at 25% of the total generation. Example of natural sources that majorly contribute to the atmosphere are (1) vegetation: when the dead vegetation decomposes, some of the carbon in soil releases to the atmosphere; (2) forest fire: when trees or biomass are burned, carbon that stored in soil is released to the atmosphere; (3) volcanic eruption: CO_2 is one of the gases released by volcanoes; and (4) ocean: absorption and release of CO_2 to the atmosphere dependent on the balance and movement of the ocean: (Casper, 2010). Therefore, the remaining amount of GHGs released (75%) is caused by human activities such as deforestation, transportation, power plant, and land use change (Zein and Chehayeb, 2015). The simulation to limit GHGs to below 2 °C relative to a pre-industrial baseline already considers the generation from both sources (Rogelj *et al.*, 2016). For mitigation, humankind needs to find ways to reduce the main types of GHG emissions, i.e., CO_2, CH_4 and N_2O (Herzog, 2006).

2.1.1 Carbon Dioxide (CO_2)

CO_2 is a colorless, and odorless gas that can absorb and emit infrared radiation. It comes from both nature and human activities. The natural sources release the gas from carbonate rocks and from volcanoes and other eruptions (Hester and Harrison, 2017). The main contributor to CO_2 of human activities is from deforestation, cement production, and the combustion of fossil fuels (Johansson *et al.*, 2012). Around 80% of the global GHG emissions is CO_2, the most relevant cause of global warming. In relation to other major GHG emissions, global warming potential (GWP) of CO_2 is usually considered as 1 due to its global GHG contribution and its lower GWP per unit molecule (Hester and Harrison, 2017).

2.1.2 Methane (CH_4)

CH_4 is a colorless gas that has an ability to ignite itself at the right temperature. The source is also from nature and human activities. The natural sources of CH_4 are contributed by wetlands, oceans, freshwater bodies, non-wetland soils, wildfires, etc. In a period of 100 years' lifetime, CH_4 has GWP more than 25 times of CO_2. CH_4 emissions are contributed by human activities from fossil fuel production, agriculture, and landfills. It is estimated that more than 50% of global CH_4 emissions released to the atmosphere is caused by human activities (Ramachandra *et al.*, 2015).

2.1.3 Nitrous Oxide (N_2O)

N_2O is a colorless and odorless gas that has a GWP more than 298 times of CO_2 in 100 years' time period. The major N_2O emissions are contributed by agricultural soil management, animal manure management, sewage treatment, mobile and stationary combustion of fossil fuel, and nitric acid production. A wide variety of biological sources in soil and water also produce N_2O, particularly from microbial action (Muthu, 2014).

2.2 Carbon

The principle amongst the GHGs is CO_2 that has been dramatically altered by human perturbations to the global cycle of carbon. Carbon is stored in the oceans about 38,400 Gt C (Gigaton of carbon); in fossil organic carbon about 4,130 Gt C; in soils about 1,200 Gt C; in the atmosphere about 720 Gt C; in plants and animal biomass about 600-1,000 Gt C (Falkowski *et al*., 2000; Sabine *et al*., 2004). Those are considered as a carbon sink because each storage pool in ocean, soil, and vegetation are taking up carbon from the atmosphere. Conversely, each storage pool is also identified as a carbon source for the atmosphere because of the constant exchange of flux between the atmosphere and the pools (Sabine *et al*., 2004).

Terrestrial vegetation stores about 610 Gt C at cellulose in the stems and branches of trees. Soil holds two to three times that much higher in the form of dead organic matter or humus. About 40% of the absorption of global CO_2 emissions is by terrestrial vegetation and soil (Adam, 2001). The terrestrial carbon uptake depends on some combination of several processes such as the fertilization of plant growth by atmospheric CO_2, and regrowth of forests in previously harvested areas (Schimel and House, 2001).

2.3 Greenhouse Gas Emissions in Thailand

Thailand is located in the Southeast Asian region which is divided into five big regions including the North, Northeast, Central, East, and South regions. The country's total land area is 514,000 km^2. Thailand's population is approximately 67 million people in 2015. Located in the tropical region, Thailand has a climate that is relatively warm and humid with three seasons including summer, rainy, and dry. The range of Thailand's temperature is 18-34 ^{0}C for the whole year (Tamang, 2016).

Thailand has recognized that climate change and its impacts could have a serious issue. According to Thailand's first biennial update report, the source of emissions is divided into five sectors including energy, industrial processes, agriculture, land use, and land-use change and Forestry (LULUCF), and waste. As presented in Figure 2.3, the total amount of GHG emissions was approximately 305.5 million t CO_2-eq in 2011. The highest GHG emissions were contributed by the energy sector (59%) generally including in almost every human activity.

There are various sub-sections of five sectors as shown in Table 2.1. Approximately 214 million t CO_2-eq was emitted by fuel combustion which was the majority of GHG emissions in the energy sector. Its major GHGs contribution consisted of public electricity and heat production (39%), transport (27%), and manufacturing and construction (20%).

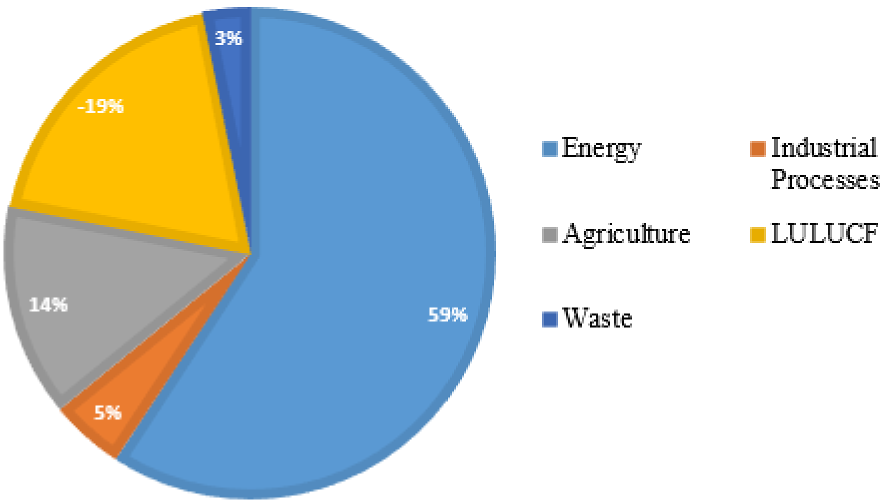

Figure 2.3 Total GHG emissions by sectors in Thailand (ONEP, 2015b)

Table 2.1 GHG emissions in Thailand from sub-sectors (ONEP, 2015b)

Source of emissions	GHGs (million t CO_2-eq)
A. Energy	
1. Fuel Combustion	213.7
• Public electricity and heat production	86.9
• Manufacturing industries and construction	44.5
• Transport	61.1
• Other sectors	21.2
2. Fugitive emissions from fuels	9.3
• Solid fuels	0.8
• Oil and natural gas	8.5
B. Industrial Processes	
1. Mineral product	17.9
• Cement production	17.7
• Soda ash production and use	0.2
• Glass production	NO
2. Chemical industry	0.3
• Nitric acid production	NO
3. Metal production	0.02
• Iron and steel	0.02
4. Other production	NO
• Pulp and paper	NO
• Food and beverage	NO
C. Agriculture	
1. Enteric fermentation	8.3
2. Manure management	3.9
3. Rice cultivation	27.2
4. Agricultural soils	11.8
5. Field burning of agricultural residues	1.8

Table 2.1 GHG emissions in Thailand from sub-sections (ONEP, 2015b) (Continued)

Source of emissions	**GHGs (million t CO_2-eq)**
D. Land Use Change and Forestry	
1. Change in forest and other woody biomass stocks	-69.3
2. Forest and grassland conservation	15.6
3. Abandonment of managed land	-17.2
4. Change in soil carbon	NE
E. Waste	
1. Solid waste disposal on land	4.9
• Landfill site	4.1
• Open dump	0.8
2. Wastewater handling	6.4
• Industrial wastewater	3.2
• Domestic wastewater	3.2
3. Waste incineration	0.1

Note: NO : not occurring, NE: not estimated

According to Figure 2.3, the second GHGs contributor was LULUCF (19%). In Figure 2.4, GHG emissions from LULUCF are presented in the gap from the years 2000 to 2011. It can be seen from the graph, there were different trends for the GHG emissions for inclusion and exclusion of LULUCF. The total of GHG emissions excluding LULUCF increased steadily between 2000 and 2007, from around 220-300 million t CO_2-eq. After that, the number slowly increased to 320 million t CO_2-eq in 2011. Meanwhile, the GHG emissions including LULUCF had lower GHG emissions than excluding LULUCF because of storage of CO_2 in soils. The total of GHG emissions including LULUCF in 2000 was 200 million t CO_2-eq and the removal of GHG emissions in the atmosphere was around 9%, considering the exclusion of LULUCF. However, from 2005 to 2011, the total of GHG emissions had a steady tendency. The gap presents the significance of this GHGs sink and source (ONEP, 2015b).

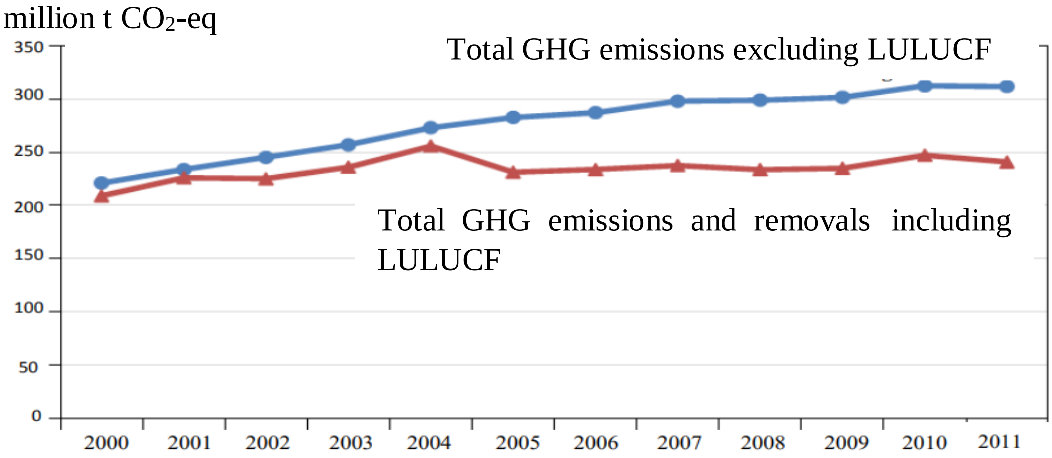

Figure 2.4 Total GHG emissions trends with and without LULUCF sector (ONEP,2015b)

For the information in details about LULUCF, as mentioned earlier, the consideration includes both carbon sink and source. Regarding the release of GHGs from this sector, it can be explained roughly by the rapid population and economic growth requiring more spaces for settlement and producing subsistent food. Then, forest and agricultural areas have been transformed. In Thailand, forest cover has decreased from 54% in 1961 to 32% in 2014. On average, the annual deforestation rate was estimated at 0.6% or 140,000 ha/year, from 1973 to 2014 (The World Bank, 2016). These land use changes certainly cause a change in soil carbon stock. This is obvious that deforestation is one of the main factors contributing to GHGs in Thailand. Thus, due to deforestation caused by land use change, it is necessary to study the carbon stock in soil. As the initial state, Phuket (as a tourist province) and Phayao (as an agricultural province) are the selected area for this study.

2.3.1 General Characteristic of Phuket Province

Phuket is located at 7°45’ - 8°15’ N and 98°15’ - 98°40’ E. The total area is 570 km^2 including the province’s other islands. It lies off the west coast of Thailand in the Andaman Sea. Phuket province is one of the top international destinations in Thailand (Euromonitor International, 2014). Tourism made up 3 billion USD or 59% of the gross provincial product (GPP) and was the biggest contributor to Phuket economy in 2013 (NESDB, 2016). For the use of land, Phuket has three districts, i.e., Thalang, Muang, and Kathu with the total of forest conservation area of approximately 33.2%, 28.2%, and 38.7%, respectively. The total of the agricultural area in these districts was about 24.6, 7.6 and 67.8%, respectively (Boupun and Wongsai, 2012). The important crops in this province were rubber, coconuts, cashews, and pineapples (Sawadee, 2018). Rubber trees were introduced in Phuket at the start of the 20th century and quickly became a specialization in agriculture. Rubber trees covered more than 40% of the island's agricultural areas (Thai residents, 2017). Anyway, the development of tourism is one of the major drivers of change in land use (Wang and Liu, 2013). This has no exception for Phuket. Land use in this province has been noticeably transformed to accommodate the growth in tourism businesses. Forest and agricultural areas have been replaced for constructing the predominant infrastructures such as shopping malls, restaurants, hotels and resorts (Prueksakorn *et al*., 2017).

2.3.2 General Characteristic of Phayao Province

The area of Phayao province is 6,335 km^2 (18^{o}44$^'$ - 19^{o}44$^'$ N; 99^{o}44$^'$ - 100^{o}40$^'$ N), at about 300 – 1,500 m above sea level. Phayao province, with an estimated population of 0.49 million in 2013, is one of the agricultural provinces in Thailand (NSO, 2013) and this province obtained 439 million USD or 42% of GPP from agricultural activities in the same year (NESDB, 2016). Around 64% of the population in Phayao province works in the agricultural sector. Agricultural land accounted for approximately 228,920 ha or 36.1% of the whole territory of the province's area. The main important plants that the society in Phayao have found economically include rice, corn (for animal feed), beans, peanuts, shallots, garlic, ginger, lychee, longan, and fisheries (Kaewsri and Traichaiyaporn, 2012; Kwan and Lake, 2014; OAE, 2015). The rice fields, farm plants, and garden plants occupy the area of 1,328; 577; and 320 km^2. The societies in Phayao province also produce the product by themselves called household industries using raw materials such as longan, aquatic animal, and hyacinth (Kaewsri and Traichaiyaporn, 2012). Among all, the major crop in Phayao is rice. It occupied around 132,798 ha or 58% of the total cultivated area (Pimmasarn *et al*., 2013). It is well realized that Phayao's agricultural land has been widely expanded (Trisurat *et al*., 2010).

2.4 GHGs in the Previous Studies

The GHG emissions for activities for provinces in Thailand have been often estimated. The emissions from open burning were studied in Phichit province of Thailand. Data were collected using field surveys and questionnaires from 144 farms (in irrigated and rainfed areas of 72 farms equally) covering two-crop years. GHG emissions were estimated based on the concept of the life cycle assessment. The estimated GHG emissions from rainfed areas contributed to higher GHG emissions than irrigated areas (Arunrat *et al*., 2016).

In assessing GHG emissions for activities in rice field in Phayao, seasonal inside irrigable, rainfall rice field, and off-seasonal practice were focused using emissions factors from 3 different sources including Country Specific Emission Factor (CSEF), 1996 IPCC Guidelines for National GHG Inventories, and from Second National Communication (SNC) report. The results showed that most of the GHG emissions were contributed by rainfall rice field (Pimmasarn *et al*., 2013). GHG emissions from livestock in Phayao province, including buffalo, meat cow, milk cow, chicken and duck were also assessed. The results showed that the emissions from enteric fermentation are the largest contributor to the farm (Muenchan and Pimonsree, 2012).

Road transportation and electricity consumption were the scopes for the studies of GHG inventory in Phuket. In 2014, diesel use was the biggest GHGs contributor (38% for scope of road transportation) (Ruengphol and Areerob, 2015). In another study, specific business (i.e. hotel, resort, and service apartment) and residential buildings sectors contributed approximately 56% for the GHGs emitted from electricity consumption of the province (Homya *et al*., 2015).

In Indonesia, there was a study showing the estimated amount of GHG emissions for both agricultural and tourist provinces, as shown in Table 2.2. Nusa Tenggara Barat (NTB) and Bali are considered as agricultural and tourist provinces, respectively. IPCC 2006 guideline was used in this estimation. The majorities of GHG emissions in NTB province were rice cultivation, livestock, biomass burning, and land use with the approximate amount at 31%, 25%, 16%, and 15%, respectively while those in Bali, were electricity use, at 58% (BPS, 2016).

Table 2.2 Major emission sources for typical agricultural and tourist areas (BPS, 2016)

The source of emissions	GHG emissions (t CO_2-eq)	
	NTB	Bali
Livestock	1,448,465	980,465
Rice cultivation	1,819,106	567,412
Biomass burning	916,573	54,107
Electricity use	654,181	2,376,222
Transportation	2,067	4,522
Industrial process	-	-
Waste disposal	58,864	56,577
Land use	881,992	54,731
Total	5,781,248	4,094,036

For LULUCF sector, the second major contributor to GWP of Thailand, there are several studied about land use change using GIS. In Phuket, the study was about land use in 2009 whether it was in accordance with the town planning policy in 2005 by using GIS overlay techniques. The land use of Phuket in 2009 was not be existent as planned while forest and agricultural areas were replaced by residential areas at 3.2% or 10.1 km^2 and 11.0% or 15.6 km^2, respectively (Boupun and Wongsai, 2012).

Another study about the assessment of land use change and its impact on ecosystem services was in Wang Thong in Phitsanulok province and Khao Kho district of Phetchaboon province in Northern Thailand. This study used GIS to identify the changes in land use from 1989 to 2013 and used Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to map and quantify a set of ecosystem services, namely sediment retention, water yield, carbon stock, and habitat quality for evaluation of impact on overall ecosystem services. The main change in land use was forests. The decease of forest cover was due to the increase of rubber plantation and built-up areas. The increase in land use types, i.e., abandoned, built-up, and rubber plantation areas visibly affected ecosystem services (Arunyawat and Shrestha, 2016).

In Bukidnon, an agricultural province in Southern Philippines, carbon stock from major types of agricultural land was estimated. The aim of the study was to estimate the actual contribution of agricultural soils in terms of carbon sink. In this study, the SOC sampling was from agricultural lands of corn, rice, sugarcane pineapple, banana, rubber, cassava, coconut, coffee, and mango. Soil data obtained in this study were analyzed by using SPSS statistical package for analysis of variance (ANOVA) to distinguish SOC stock among land use categories. The highest SOC sequestered in this study was from soils of rubber and coconut plantation at approximately 37.10 MgC/ha and 30.30 MgC/ha, respectively while the lowest was from that of pineapple plantation at 14.7 MgC/ha (Patricio, 2014).

CHAPTER 3
METHODOLOGY

3.1 Conceptual Frameworks

The conceptual framework of this study is shown in Figure 3.1. Carbon stock from land use change in the years 2007 and 2009 was estimated for Phuket and Phayao provinces using IPCC 2006 guideline. The reason behind the selected years is for the fair comparison of both provinces, mainly based on the availability of data from governmental sources (LDD), for identifying land use change through land use matrix.

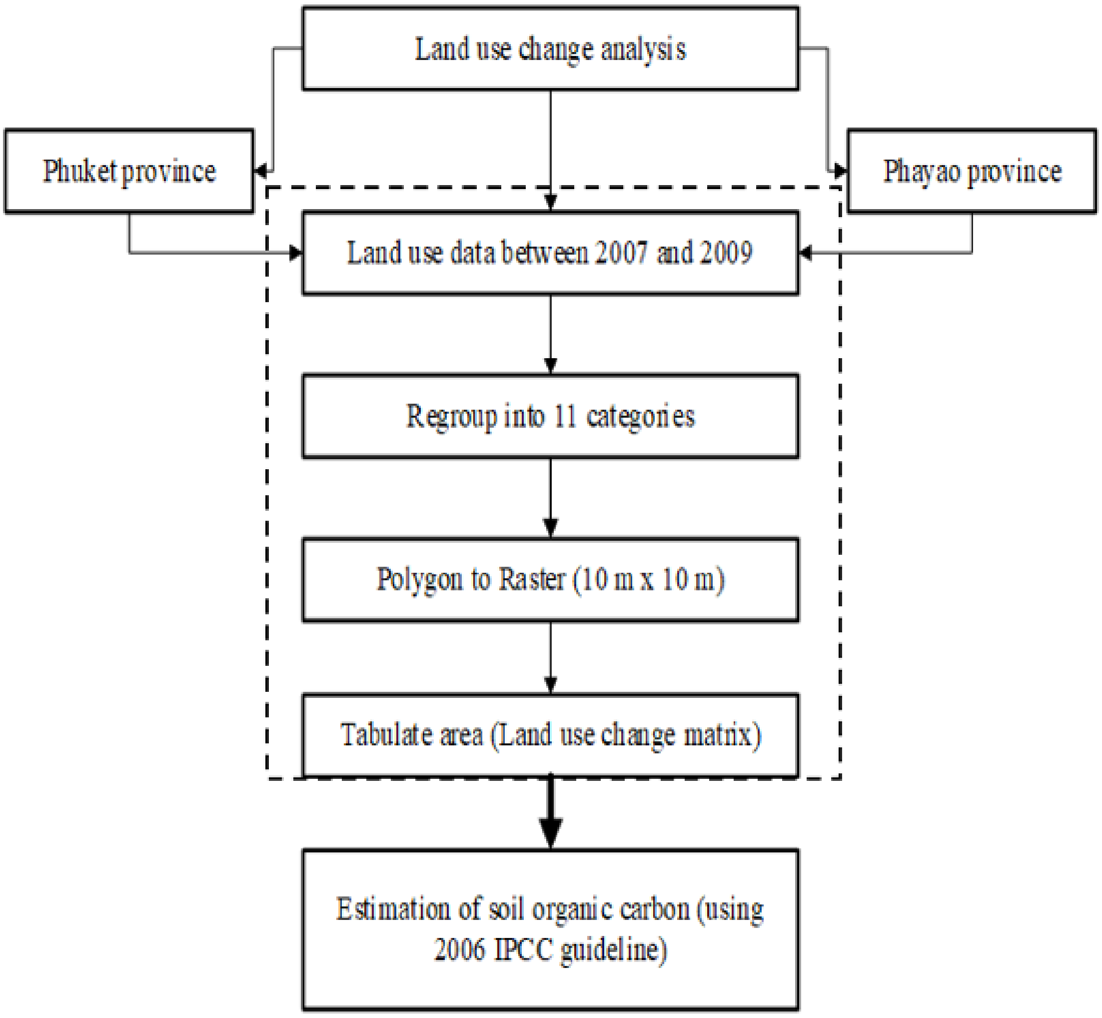

Figure 3.1 Flow chart of research process

3.2 Study Area

The study areas of this research are Phayao and Phuket provinces as shown in Figure 3.2. Phayao, an agricultural province, is located in the Northern Thailand. Phuket province, a tourist province, is located in the Southern Thailand.

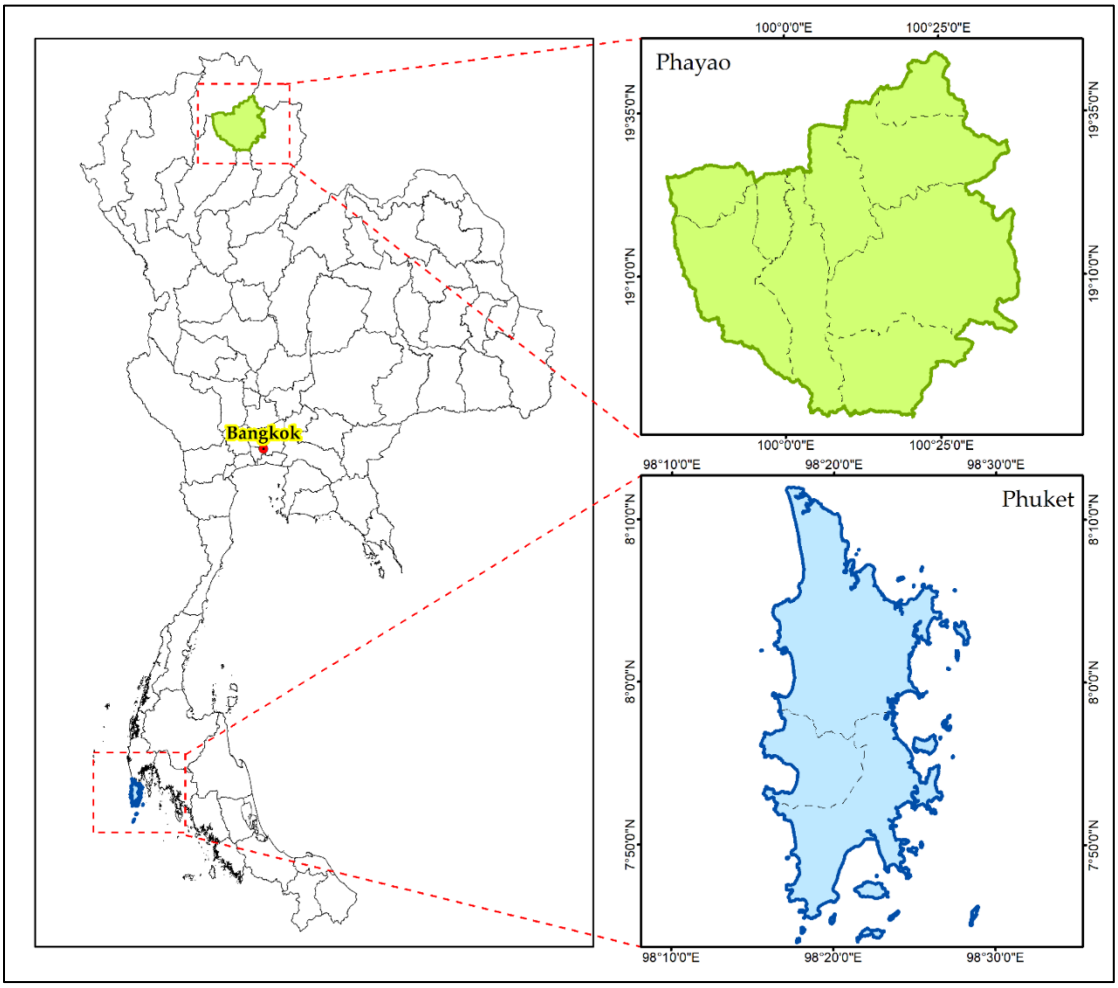

Figure 3.2 The study areas

3.3 Calculation Method

To estimate soil carbon stock in Phuket and Phayao provinces, the data collection of land use in 2007 (LU2007) and 2009 (LU2009) were obtained from LDD (LDD, 2016). 85 different land use types in the data obtained from LDD for both provinces were regrouped into 11 main groups, i.e., evergreen forest, other forest (such as dense deciduous forest, disturb forest, and beach forest), paddy field, perennial land (such as rubber, oil palm, coconut, longan, etc.), other agricultural land, golf course, grassland, water body, aquaculture land, settlements, and other land. This regroup was considered based on 2006 IPCC guideline and land characterization of Phuket and Phayao to represent the characteristics of tourist and agricultural provinces. After the process of regrouping, land use data stored as polygon were converted into raster data using maximum combined area algorithm with the cell size 100 m^2. Then grid analysis was utilized to observe the change from LU2007 to LU2009 by using ArcGIS 10.3 software.

Based on the 2006 IPCC formula, the following Eq. (1) was used in this study to estimate carbon stock in Phuket and Phayao provinces.

$$SOC = SOC_{REF} \cdot F_{LU} \cdot F_{MG} \cdot F \cdot A \qquad (1)$$

where SOC is the total of organic carbon stored in soil in the years 2007 and 2009 (t C); SOC_{REF} is the reference carbon stock (t C/ha); F_{LU}, F_{MG} and F are the stock change factors for types of land used, the management system, and the input of organic matter, respectively (dimensionless); A is the area of land used (ha). The land use data were shown in Appendix C (Table C.1 and Table C.2) for Phuket and Appendix D (Table D.1 and Table D.2) for Phayao. The stock change factors were shown in Appendix C: Table C.3 for Phuket and Appendix D: Table D.3 for Phayao.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Land Use Change

4.1.1 Land Use Change in Phuket Province

The land use in Phuket province for the years 2007 and 2009 is shown in Figure 4.1. It illustrates that the agricultural lands were the majority of land use in Phuket province (approximately 40% of the total area). Rubber plantation area occupied the largest share of agricultural land, followed by coconut, other agricultural area (mainly oil palm), and paddy field. Settlements areas, i.e., city/town/commercial, village, and other urban areas accounted for the second-largest proportion of land use in this province. The third-largest land use of the province was forest areas which covered 20% of the total land. Other land use categories such as golf course, grassland, reservoir, other water body, other land covered less than 10% of the total area. As being affected by economic growth, there was an opposite direction between upward trend of urban areas and downward trend of green areas (forest and agricultural areas) from 2007 to 2009.

Table 4.1 shows the slight decline of the mangrove area (approximately 0.7 km^2, decreasing from 30.8 km^2 to 30.1 km^2). The area of evergreen forest and deciduous forest between 2007 and 2009 decreased from 95.9 km^2 to 92.5 km^2 and 5.2 km^2 to 4.9 km^2, respectively. These areas were mainly replaced by urban areas, i.e., village (3.4 km^2 of evergreen forest and 0.4 km^2 of deciduous forest). The falling down of green areas was due to tourism-based development, i.e., urban expansions. Many hotels were built in the forest conservation areas due to requirements for slope areas or hillsides that can serve the sea sightseeing (Boupun and Wongsai, 2012). Paddy field of the province declined approximately 0.9 km^2 (from 3.3 to 2.4 km^2) between 2007 and 2009. The area of rubber, grassland, coconut, animal farm, other agricultural area, and other land declined around 4.1, 1.9, 1.0, 0.9, and 0.4 km^2 between 2007 and 2009, respectively. These areas were mostly changed into village. Villages were the largest increase (approximately 48.1 km^2). Due to tourism growth, the land use of golf course, reservoir, other water body, and city/town/commercial rose approximately 3.6, 1.2, 0.2, and 0.04 km^2 between 2007 and 2009. The rise of golf course was caused by the cheaper fee for this activity compared to other countries. In Phuket's golf courses, the golfers do not need to show handicap cards and the rule is not quite strict. Moreover, the golfers could enjoy Phuket's year-round mild climate, beautiful beaches, and relaxed atmosphere (The signature collection, 2016).

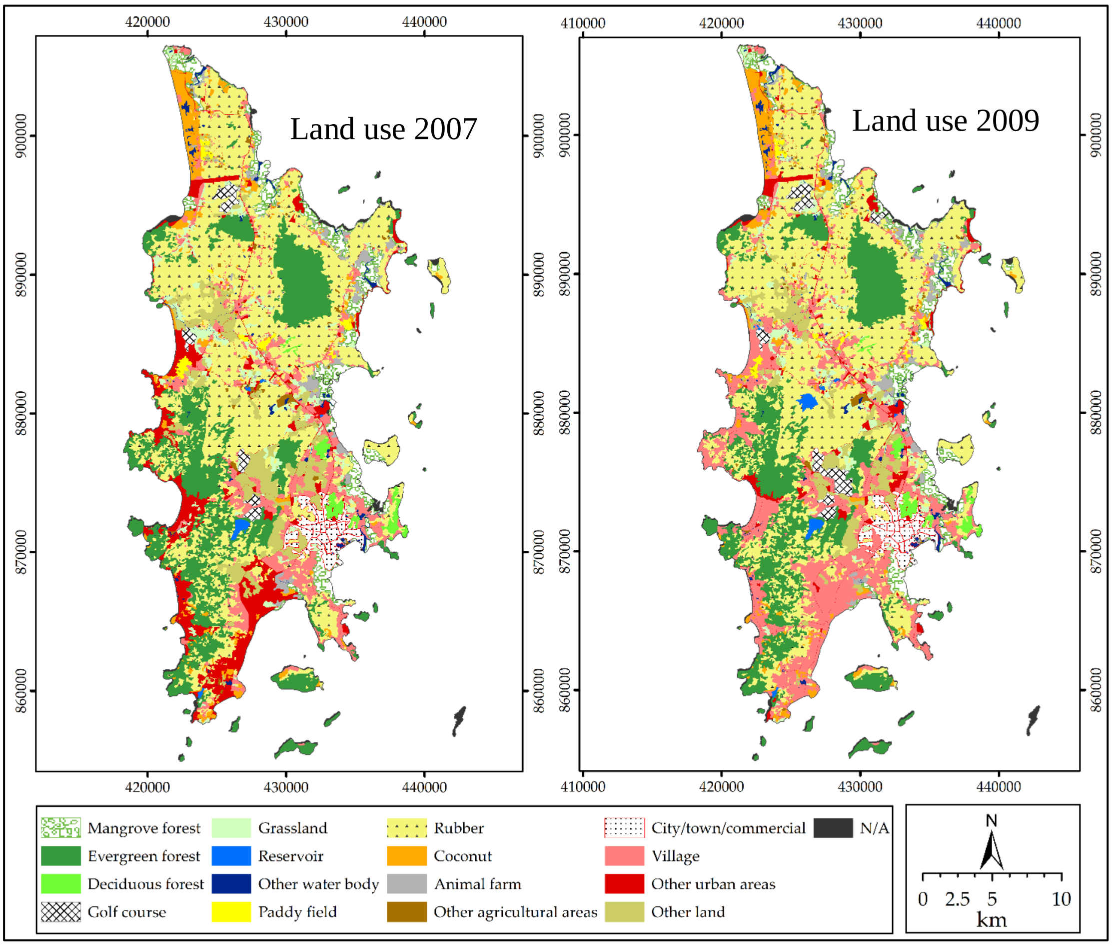

Figure 4.1 Land use change in Phuket province between 2007 and 2009

Table 4.1 Land use change matrix for Phuket province for the years 2007 and 2009

Types of land use	Land use 2009																			Total
	1	**2**	**3**	**4**	**5***	**6**	**7**	**8***	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	NA	
Land use 2007 **1**	30.1	0.0	0.0	0.0	-	0.01	0.0	-	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.3	0.02	0.0	0.0	30.8
2	0.0	92.5	0.0	0.0	-	0.3	0.0	-	0.0	0.01	0.0	0.0	0.0	0.0	0.0	3.0	0.1	0.0	0.0	95.9
3	0.0	0.0	4.9	0.0	-	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	5.2
4	0.0	0.0	0.0	2.4	-	0.02	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.3	0.0	3.3
5*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.1	0.0	0.0	0.0	-	195.7	0.1	-	0.0	0.5	0.5	0.1	0.8	0.01	0.0	3.2	0.2	0.3	0.0	201.5
7	0.0	0.0	0.0	0.0	-	0.2	16.9	-	0.0	0.2	0.0	0.04	0.0	0.0	0.0	0.9	0.1	0.0	0.0	18.2
8*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	0.0	0.0	0.0	0.0	-	0.4	0.0	-	9.0	0.0	0.0	0.01	0.0	0.0	0.0	0.4	0.0	0.3	0.0	10.0
10	0.0	0.0	0.0	0.01	-	0.5	0.1	-	0.0	2.6	0.0	0.01	0.1	0.0	0.0	0.4	0.0	0.0	0.0	3.6
11	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8
12	0.0	0.0	0.0	0.0	-	0.1	0.0	-	0.0	0.01	0.0	14.7	0.0	0.0	0.04	2.4	0.1	0.3	0.0	17.6
13	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	1.4
14	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0	4.9
15	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	12.8
16	0.0	0.0	0.0	0.0		0.1	0.1	-	0.0	0.01	0.0	0.03	0.0	0.0	0.0	46.1	0.4	0.0	0.0	46.7
17	0.0	0.0	0.0	0.0	-	0.02	0.02	-	0.1	0.0	0.0	0.02	0.0	0.0	0.0	29.5	15.4	0.0	0.0	45.1
18	0.0	0.0	0.0	0.0	-	0.1	0.0	-	0.0	0.04	2.8	0.7	0.4	0.0	0.0	7.7	0.6	22.2	0.0	34.5
NA	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	9.1	9.3
Total	30.1	92.5	4.9	2.4	-	197.4	17.2	-	9.1	3.2	9.4	15.7	2.7	5.2	12.9	94.8	16.9	23.4	9.1	546.9

1) Mangrove forest, 2) Evergreen forest, 3) Deciduous forest, 4) Paddy field, 5) Corn, 6) Rubber, 7) Coconut, 8) Longan, 9) Animal farm, 10) Other agricultural area, 11) Golf course, 12) Grassland, 13) Reservoir, 14) Other water body, 15) City/town/commercial, 16) Village, 17) Other urban area, and 18) Other land.

4.1.2 Land Use Change in Phayao Province

The changes in Phayao land use between 2007 and 2009 are presented in Figure 4.2. Forest area, i.e., evergreen and deciduous forests occupied the majority of land use in Phayao province (approximately 46% of the total land area). The second-largest share of land use was agricultural area. It covered about 35% of the whole province. There were several types of crops in agricultural areas, i.e., paddy field (19%), corn (11%), longan (2%), other agricultural area (2%), rubber (0.41%), animal farm (0.17%), and coconut (0.001%). The settlement areas shared the smallest proportion of land use with approximately 4% of the total area. The remaining parts of Phayao land use were golf course, grassland, reservoir, other water body, and other land.

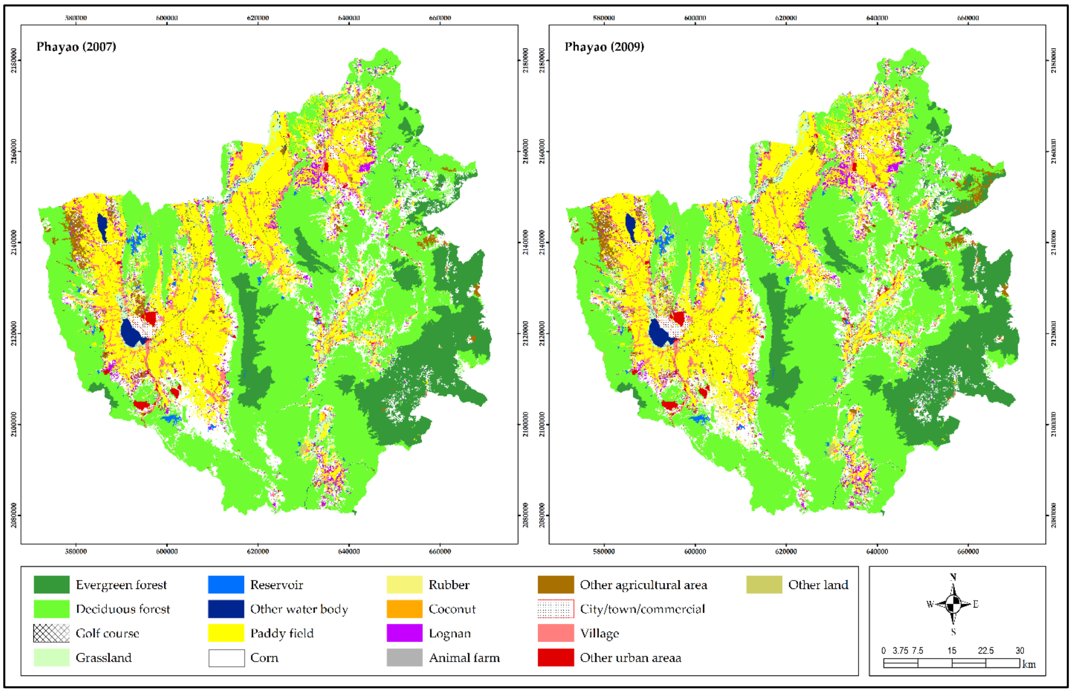

Figure 4.2 Land use change in Phayao province between 2007 and 2009

Based on the information in Table 4.2, there was a slight change in Phayao land use. The most significant decrease in land use was corn plantation. From 2007 to 2009, it decreased from 701.7 to 655.0 km^2. Corn plantation was mainly transformed into rubber plantation, other agricultural area, and longan.

Table 4.2 Land use change matrix in Phayao province for the years 2007 and 2009

Types of land use		Land use 2009																		Total
		1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Land use 2007	1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	814.8	0.0	0.0	4.4	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	819.9
	3	-	0.0	2,674.4	0.6	22.6	3.2	0.0	0.5	0.0	2.3	0.0	0.7	0.0	0.04	0.0	0.0	0.0	0.1	2,704.3
	4	-	0.0	0.0	1,174.6	3.3	1.7	0.01	1.1	0.5	1.5	0.0	0.1	0.1	0.0	0.0	0.4	0.2	0.4	1,183.8
	5	-	0.0	1.5	1.2	614.3	37.1	0.1	9.6	0.2	34.7	0.0	2.0	0.0	0.01	0.0	0.02	0.1	1.1	701.7
	6	-	0.0	0.0	0.0	0.0	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.2
	7	-	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
	8	-	0.0	0.0	0.1	1.6	3.7	0.0	125.9	0.01	7.1	0.0	0.03	0.0	0.0	0.0	0.01	0.01	0.02	138.4
	9	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	10.3
	10	-	0.0	0.0	0.1	5.0	3.6	0.1	0.8	0.1	111.5	0.0	0.6	0.0	0.0	0.0	0.1	0.0	3.6	125.4
	11	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
	12	-	0.0	0.0	0.1	3.8	1.1	0.01	0.5	0.1	1.8	0.0	155.2	0.02	0.0	0.0	0.04	0.1	0.1	162.8
	13	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.4	0.02	0.0	0.0	0.0	0.0	29.4
	14	-	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.4	0.0	0.0	0.0	0.0	53.4
	15	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.9	0.0	0.0	0.0	38.9
	16	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	141.1	0.0	0.0	141.1
	17	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.3	0.1	38.4
	18	-	0.0	0.0	0.03	0.2	0.03	0.0	0.02	0.0	0.4	0.0	0.9	0.0	0.0	0.0	0.03	0.1	13.1	14.8
Total		-	814.8	2,675.8	1,176.6	655.0	75.7	0.2	138.4	11.2	159.9	0.02	159.5	29.5	53.5	38.9	141.6	38.8	18.5	6,187.8

1) Mangrove forest, 2) Evergreen forest, 3) Deciduous forest, 4) Paddy field, 5) Corn, 6) Rubber, 7) Coconut, 8) Longan, 9) Animal farm, 10) Other agricultural area, 11) Golf course, 12) Grassland, 13) Reservoir, 14) Other water body, 15) City/town/commercial, 16) Village, 17) Other urban area, and 18) Other land.

The second largest decrease of land use belonged to deciduous forest (from 2,704.3 to 2,675.8 km^2). The area of paddy field, evergreen forest, and grassland decreased by approximately 7.2, 5.2, 3.3 km^2, respectively. It is noted that the decrease in areas of paddy field was mainly caused by the transformation into the plantation of corn, rubber, longan, and other types of land use. The vast area of paddy field and corn plantation were transformed into rubber plantation because Northern Thailand's provinces (e.g., Phayao) were the potential suppliers of this raw material to Southern China. Therefore, the Royal Thai Government (RTG) continued to support farmers to grow this crop through subsidies and technical assistance. The RTG had a policy to support the expansion of rubber areas, a policy initiative fueled by southern China's growing demand for rubber. Phayao province became the birthplace of former Prime Minister Thaksin's "One Million Rai" policy, which sought to cultivate approximately 160,000 ha of rubber plantations (WikiLeaks, 2009). Therefore, the rubber plantation increased from 25.2 to 72.7 km^2.

The area of other agricultural area, other land, animal farm, coconut, and longan increased from 125.4 to 159.9 km^2, 14.8 to 18.5 km^2, and 10.3 to 11.2 km^2, 0.04 to 0.2 km^2, and 138.4 to 138.4 km^2 respectively. Waterbody including reservoir and other water body remained steady in these 3 years at about 29 km^2 and 53 km^2, respectively. The surface water resource in Phayao is Kwan Phayao which is the third largest of the freshwater resource. Water from reservoir drain into this lake. Kwan Phayao has an average water volume of 33.8 million m^3. Water from this lake is normally utilized by the communities for household consumption and agricultural purposes (Kaewsri and Traichaiyaporn, 2012). Since Phayao is an agricultural province and this province experienced drought in 2016 (Bangkok post, 2016), the expansion of water body should be paid more attention to ensure that the water supply is enough for residents and agricultural activities. Others such as golf course, city/town/commercial, village, other urban areas, and other land were remaining stable between 2007 and 2009. Since Phayao province is not a coastal area, the land use of mangrove forest was not available.

4.2 Comparative of Land Use Change between Phuket and Phayao Provinces

Figure 4.3 shows changes in land uses in Phuket and Phayao provinces between 2007 and 2009, for mangrove forest, evergreen forest, deciduous forest, paddy field, corn, rubber, coconut, longan, animal farm, other agricultural area, golf course, grassland, reservoir, other water body, city/town/commercial, village, other urban area, and other land.

In Phuket, the land use types that increased the most were village and golf course by 48.1 km^2 (45.2% of the total change area) and 3.6 km^2 (3.4 % of total change area), respectively. Those were higher than Phayao which increased by only 0.1 km^2 (0.3% of the total area) for village. The remaining increase in the area of Phuket was reservoir, other water body, and city/town/commercial with 1.2, 0.2, and 0.04 km^2, respectively. In Phuket, other urban, other land, and evergreen areas decreased significantly in this period, shrinking by 28.2 km^2 (26.5%), 11.1 km^2 (10.5%), and 3.4 km^2 (3.2%), respectively. Also, rubber plantation and other agricultural area declined by 4.1 km^2 (3.8%) and 0.4 km^2 (0.4%). The area of grassland, coconut plantation, animal farm, paddy field, and mangrove forest areas also dropped by 1.9, 1.0, 0.9 and 0.7 km^2, respectively. The plantation of corn and longan in Phuket had no change in the period of this study.

In Phayao, rubber plantation and other agricultural area increased the most by approximately 50.5 km^2 (27.8%) and 34.5 km^2 (19.0%), respectively. Other land expanded the area approximately 3.7 km^2 (equal to 2.0%). Otherwise, the remaining increase in the land use was animal farm (0.9 km^2), coconut (0.1 km^2), other urban area (0.5 km^2), reservoir (0.1 km^2), and other water body (0.1 km^2). The most significant decrease in area in Phayao was corn plantation with 46.66 km^2 (25.7%) and deciduous forest with 28.5 km^2 (15.7%). There was also a decline in the area of other urban (0.5 km^2 or 0.3%) and evergreen areas (5.2 km^2 or 0.1%), paddy field (7.2 km^2) and grassland (3.3 km^2). Longan plantation was stable in this period, as well as there was no change in area of golf course and city/town/commercial in this period.

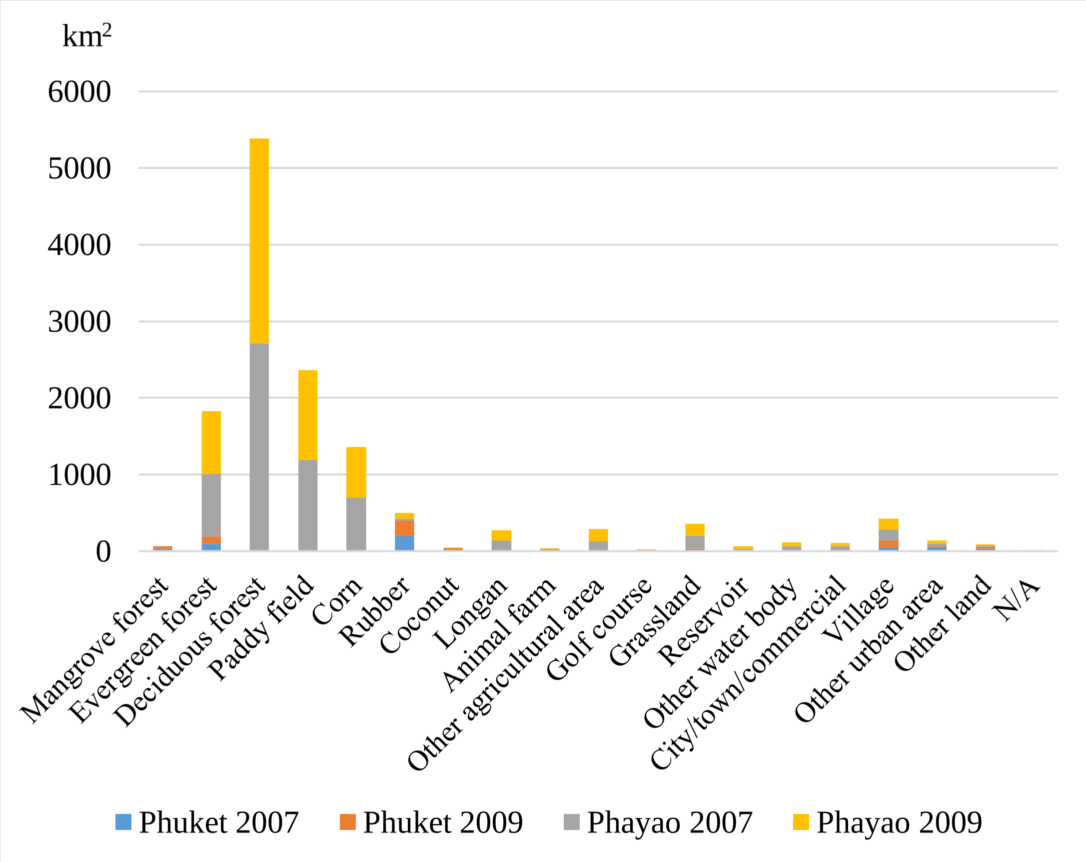

Figure 4.3 The comparison of land use change between Phuket and Phayao provinces

4.3 Soil Organic Carbon

4.3.1 Carbon Stocks in Phuket Province

Carbon stock change caused by the land use change in Phuket province is presented in Table 4.3. The soil carbon stock of evergreen forest and rubber was approximately 53.1% and 30.9%, respectively. Those types of land use had the higher carbon stock in soil than other types of land use. However, in 2009, the carbon stock in soil of evergreen forest and rubber plantation decreased, remarkably. In 2009, the carbon stock of mangrove forest, grassland, deciduous forest, coconut, golf course, and paddy field was approximately 8.8%, 2.5%, 2.0%, 1.8%, 0.7%, and 0.1%, respectively.

The loss in carbon stocks in soil in the period 2007 and 2009 in Phuket province was around 130,000 t C, consisting of the losses in approximate carbon stocks of evergreen forest (81,000 t C), rubber (27,000 t C), mangrove forest (8,000 t C), grassland (13,600 t C), deciduous forest (6,500 t C), coconut (4,500 t C), and paddy field (900 t C). However, the province gained carbon stocks in soil from golf course. This is caused by the increase of golf course area from 5.8 km^2 in 2007 to 9.4 km^2 in 2009.

Table 4.3 Carbon stocks in soil in Phuket province between 2007 and 2009

Land use types	Carbon stock (t C)		Carbon stock change (t C)
	2007	2009	
Mangrove forest	376,345.2	368,280.7	-8,064.5
Evergreen forest	2,283,372.0	2,202,452.0	-80,920.0
Deciduous forest	90,128.0	83,592.0	-6,536.0
Paddy field	3,270.0	2,360.0	-910.0
Corn	-	-	-
Rubber	1,329,768.0	1,302,708.0	-27,060.0
Coconut	80,477.7	75,972.4	-4,505.3
Longan	-	-	-
Golf course	17,601.6	28,636.8	11,035.2
Grassland	116,820.6	104,223.6	-12,597.0
Total	4,297,783.1	4,168,225.5	-129,557.7

4.3.2 Carbon Stocks in Phayao Province

Carbon stocks from land use change in Phayao are presented in Table 4.4. Dense deciduous forest covers the large area of forest in Northern Thailand (Kaewkrom *et al.*, 2011). In this province, dense deciduous forest had the highest carbon stock in soil. However, due to deforestation for expansion of agricultural areas, the soil carbon stock in Phayao was changed. In 2007, the carbon stocks in deciduous forest, evergreen forest, paddy field, corn, grassland, longan, rubber, coconut, and golf course were approximately 65.2%, 27.3%, 3.8%, 1.7%, 1.5%, 0.39%, 0.1%, 0.0002%, and 0.00001%, respectively. In 2009, the carbon stocks in deciduous forest, evergreen forest, paddy field, corn, grassland, longan, rubber, coconut, and golf course were approximately 65.0%, 27.4%, 3.8%, 1.6%, 1.5%, 0.4%, 0.4%, 0.0008%, and 0.00001%, respectively. The carbon stock in rubber plantation area increased 3 times in 2009. This was caused by the increase in rubber land in this province from 25.2 km^2 in 2007 to 75.7 km^2 in 2009.

The loss of carbon stocks in soil in Phayao between 2007 and 2009 was around 546,000 t C consisting of the losses in approximate carbon stocks of deciduous forest (491,000 t C), evergreen forest (123,000 t C), paddy field (16,000 t C), corn (81,700 t C), and grassland (22,000 t C). Rubber (187,000 t C), coconut (400 t C), and longan (20 t C) gained the carbon stocks due to the increase in the area of these land use types.

Table 4.4 Carbon stocks in soil in Phayao province between 2007 and 2009

Land use types	Carbon stock (t C)		Carbon stock change (t C)
	2007	2009	
Mangrove forest	-	-	-
Evergreen forest	19,514,096.0	19,391,050.0	-123,046.0
Deciduous forest	46,514,648.0	46,023,932.0	-490,716.0
Paddy field	2,687,135.2	2,670,904.7	-16,230.5
Corn	1,227,940.0	1,146,285.0	-81,655.0
Rubber	93,566.2	280,884.1	187,317.9
Coconut	121.2	545.4	424.2
Longan	280,732.4	280,752.7	20.3
Golf course	7.1	7.1	0.0
Grassland	1,079,165.1	1,057,219.8	-21,945.3
Total	71,397,411.2	70,851,580.8	-545,830.4

CHAPTER 5
CONCLUSION

Land use change directly affected the stocks of carbon in soil. The goals of this study were to estimate the change of land use in Phuket and Phayao provinces between 2007 and 2009 and the change of the carbon stocks in soil, accordingly, in different land use types including mangrove forest, evergreen forest, deciduous forest, paddy field, corn, rubber, coconut, longan, animal farm, other agricultural area, golf course, grassland, reservoir, other water body, city/town/commercial, village, other urban area, and other land.

The results showed that carbon stock in Phuket between 2007 and 2009 was mostly in evergreen forest, rubber plantation area, mangrove forest, and deciduous forest. In Phayao, carbon stock was mostly in deciduous forest, evergreen forest, paddy field, corn, and grassland. The Phuket and Phayao's major changes of carbon stocks were due to the transformation of land to urban areas and agricultural areas, respectively. So as to attain the approaches for maintaining the balance of global carbon, not to have CO_2 too much in the atmosphere, this preliminary study provide the detailed information about the major changes of carbon stocks and losses with the wish that it can be helpful for the further studies in related topics.

CHAPTER 6
RELATED AND FUTURE WORKS

6.1 Work Related to the Publication

6.1.1 Research Objectives and Scope

The research objectives of work related to the publication are to estimate GHG emissions from agriculture (i.e. biomass burning and rice cultivation), livestock, transportation, and industrial process sectors in Phayao province. The research scope of additional work includes the GHG emissions are presented in the unit of CO_2-eq. IPCC 2006 guideline was used in this study for calculating GHG emissions. The study area is in Phayao province – as a representative of agricultural province. The secondary data of the sectors were collected from governmental organizations in Phayao province in the period 2012/2013.

6.1.2 Methodology

6.1.2.1 Conceptual Frameworks

The conceptual frameworks of this study are shown in Figure 6.1. The additional work was estimated in this study consisted of agriculture (i.e. biomass burning, rice cultivation, and livestock), transportation, and industrial process sectors.

6.1.2.2 Activity Data

To estimate GHG emissions, data for the estimation of GHG emissions for Phayao province were obtained from many sources including governmental organizations. Major source of emissions was found from agriculture (i.e. biomass burning, rice cultivation, livestock), transportation, and industrial process sectors.

The data collection of biomass burning including forest fire and agricultural residues i.e. rice and corn were gotten from the Moderate Resolution Imaging Spectroradiometer (MODIS) to identify the location and size of the burn (NASA, 2012). The EF of biomass burned as shown in Appendix E: Table E.2 (Kanabkaew and Oanh, 2011). The data collection of rice cultivation was acquired from Phayao Provincial Agricultural Extension Office as shown in Appendix E: Table E.5 (DOAE, 2011).

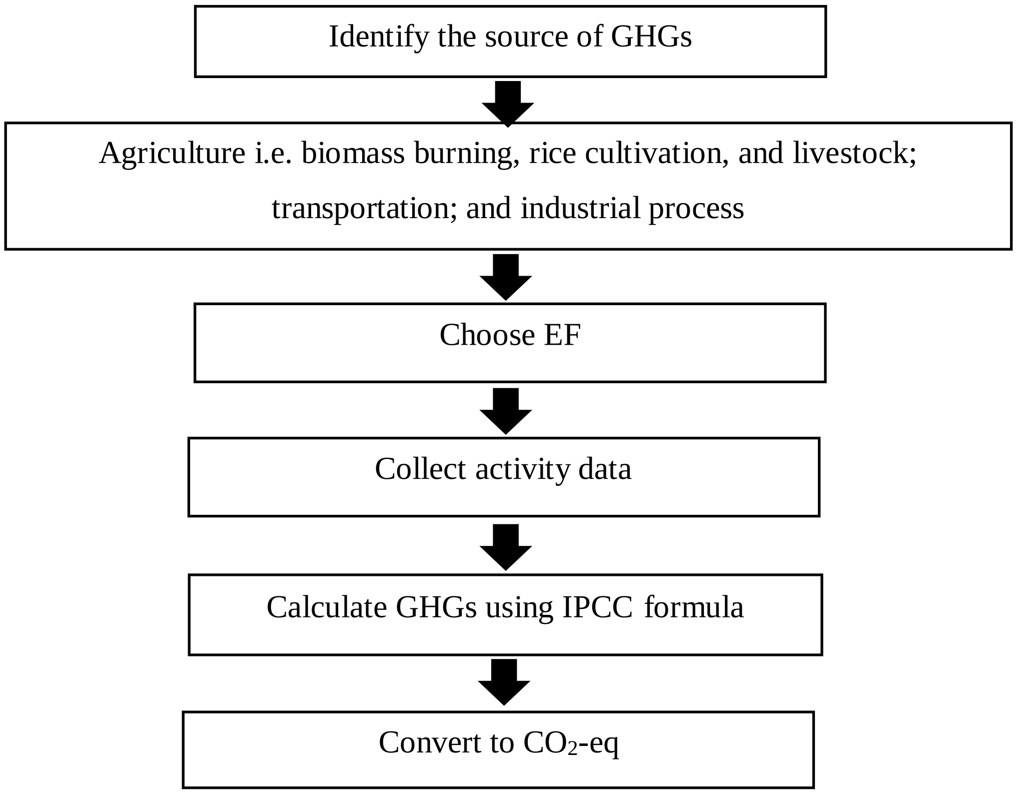

Figure 6.1 Flow chart of work related to the publication

The EF values for rice cultivation were collected from the 2006 IPCC Guidelines for National GHG Inventories, as shown in Appendix E: Table E.6 (IPCC, 2006). The data collection from livestock was provided by the provincial livestock office and site survey (Muenchan and Pimonsree, 2012). The EF values from livestock were collected from the IPCC, as shown in Appendix E: Table E.7 and E.8 (IPCC, 2006). To estimate GHG emissions from transportation sector, the data collection of traffic, car speed, registered car, and fuel used were derived from Department of Highway (DOH, 2012), Highway Police Division (HPD, 2012), Department of Land Transport (DLT, 2012), and Ministry of Energy (MOE, 2012). Fuel used, year of cars and type of cars were used to determine the EF values for transportation sector, the data were obtained from the research project studied in Bangkok, Thailand, as shown in Appendix E: Table E.12 (ESMAP, 2009). Continuously, industry sector was investigated in this study where the data were collected from Phayao Province Industry

Office (PIO, 2012). The EF for industry was gotten from United States Environmental Protection Agency (US EPA), as shown in Appendix E: Table E.14 (US EPA, 2005).

6.1.2.3 Calculation Method

The final results of GHG emissions from various sectors were expressed in terms of CO_2 equivalent (CO_2-eq) by multiplying the mass of gas and GWP. The GWP of major GHGs for 100 years' period are 1 for CO_2, 25 for CH_4, and 298 for N_2O, (IPCC, 2007a).

6.1.2.4 Agriculture

6.1.2.4.1 Biomass Burning

In this study, biomass burning emissions from residues (this study was referred to those burned in fields and forests) were initially calculated at the provincial level by using Eq. (2).

$$E_1 = EF_1 \cdot M \qquad (2)$$

Where E_1 is the amount of CO_2 or CH_4 from biomass burning **(**t CO_2 or t CH_4, respectively**)**, M is the amount of biomass burned ($kg_{dry\ mass}$), EF_1 is EF for GHGs emitted from different crops (t CO_2 or t $CH_4/kg_{dry\ mass}$). To determine the amount of biomass (M), two methods were used based on the formula below. The amount of biomass burned in the forest area was calculated by using Eq. (3) whilst that in the agricultural area was calculated by using Eq. (4).

$$M = A_1 \cdot B \cdot C \qquad (3)$$

Where A_1 is the burned area of forest (km^2), B is the biomass density in the forest area ($kg_{dry\ biomass}/km^2$), and C is burning efficiency.

$$M = P \cdot N_1 \cdot D \cdot \beta \cdot F_1 \qquad (4)$$

Where P is the amount of crop production (kg), N_1 is the residue to crop ratio, D is dry matter to crop residue ratio, β is the fraction burned of agriculture in the field, and F_1 is the crop specific burn efficiency ratio (IPCC, 2006).

6.1.2.4.2 Rice Cultivation

To estimate emissions from rice cultivation, the Eq. (5) were used based on the IPCC (IPCC, 2006).

$$E_2 = EF_2 \cdot t \cdot A_2 \qquad (5)$$

where E_2 is the amount of CH_4 emissions during processing the rice (t CH_4), EF_2 is the emission factor (t CH_4 /ha/day), A_2 is the cultivation area (ha), and t is the harvesting period of rice (day).

6.1.2.4.3 Livestock

The emissions from enteric fermentation and manure management from livestock release emissions to the atmosphere were estimated by using Eqs. (6) and (7).

$$E_3 = EF_3 \cdot N_2 \quad (6)$$

where E_3 is the amount of CH_4 emission from enteric fermentation and manure management (t CH_4), EF_3 for enteric fermentation and manure management is the EF obtained from the IPCC 2006 (t CH_4/head), N_2 is head number of each type of livestock (head).

N_2O emissions from direct emission are caused by manure management. The emissions were estimated by using Eq. (7).

$$N_2O_D = \left[\sum_S \left[\sum_T \left(N_3 \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] \cdot EF_4\right] \cdot \frac{44}{28} \quad (7)$$

where N_2O_D is the direct N_2O emissions from manure management (t N_2O), N_3 is the head number of each type of livestock T (head), T is the type of livestock. $Nex_{(T)}$ is the annual average nitrogen excretion of each type of livestock T (t N/ head), $MS_{(T,S)}$ is the fraction of the total annual nitrogen excretion for each type of livestock T which is applied in S which is the manure management system, EF_4 is the EF from manure management system (t N_2O-N/t N), and 44/28 is the conversion factor to convert from (N_2O-N) emissions to N_2O emissions.

6.1.2.5 Transportation

The calculation of emissions from the transport sector was done using the following Eqs. (8) and (9).

$$E_4 = EF_5 \cdot A_3 \quad (8)$$

where E_4 is the amount of emissions (t CO_2), A_3 is the activity data of emissions from transport (km), and EF_5 is the EF from transport (t CO_2/km).

$$A_3 = \sum [(N_4 \cdot Y \cdot F_2) \cdot distance] \quad (9)$$

where N_4 is the number of car, Y is the proportion by year of car, and F_2 is the proportion by type of fuel (IPCC, 2006).

6.1.2.6 Industrial Process

The emissions from the industrial process sector are calculated by using Eq. (10).

$$E_5 = EF_6 \cdot A_4 \cdot \left(\frac{1\text{-}ER}{100}\right) \qquad (10)$$

where E_5 is the amount of CO_2 emissions (t CO_2), A_4 is the activity data of emission source (Mg), EF_6 is EF from the industrial process (t CO_2/Mg), and ER is overall emission reduction efficiency (%) (US EPA, 2005).

6.1.3 The Summary of Results

The result of GHG emissions in Phayao province is based on paper entitled “Inventory of GHG emissions for Phayao province – an agricultural city in Thailand” (Appendix B). It was found that the highest GHG emissions in Phayao were from biomass burning which was approximately 62% of the total GHG emissions. This is because the total amount of biomass that was burned in Phayao Province in 2012 was 1.07 million t. It was divided into 50 thousand t of agricultural residues burned and 1.02 million t of biomass burned in the forest areas. For the amount of agricultural residues burned, it was separated by the type of biomass burned. It was found that the most biomass burned was 4.53 t of rice and 3.02 t of corn. The high biomass burning was also caused by the weather. In this study, the biomass burned during dry season in January, February, March, April, and December which had a chance of fire easily.

The cultivation process of rice also released GHG emissions to the atmosphere which was around 26% of the total GHG emissions. It was the second-highest emissions source. It was caused by the high CH_4 emitted during rice cultivation. The CH_4 emission is one of the GHG emissions which is produced through anaerobic decomposition organic material in rice field. Apart from that, GHG emissions from agriculture could be also produced by livestock which was around 4.60% of the total GHG emissions. GHG emissions from livestock were contributed from enteric fermentation and manure management.

In Phayao, GHG emissions also could be created by transportation which was around 6.70%. This is because the data were collected on Thursday, Saturday, and Sunday which were public holidays. It had more traffic than usual day which emitted more GHG emissions to the atmosphere. In this study, industry also contributed GHG emissions approximately 0.20% of the total emissions. It was the lowest GHG emissions rolled in this province.

6.2 Future Work

Our research team is conducting works with similar methodology for a longer period of data analysis from 2012 to 2016. The identification of GHG emissions is hopefully expanded to the sectors of energy (i.e. fuel consumption and electricity use), land use change, industry processes, agriculture (i.e. biomass burning, rice cultivation, and livestock), and waste disposal.

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APPENDIX A

Publication I

Estimation of Carbon Stocks from Land-use Change due to Tourism in Phuket Island, Thailand

331

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Estimation of Carbon Stocks from Land-use Change due to Tourism in Phuket Island, Thailand

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According to the National Statistical Office (NSO) and the Phuket Provincial Statistical Office (PPSO), Phuket Island records a high growth rate for tourism, indicating the importance in local and national economic development. The tourism industry created noticeable effect on economic, social and also on the environmental systems. The growth of the tourism industry in Phuket has resulted in significant changes to the island, especially in the urban structure, causing problems for local citizen such as serious traffic congestion, cost-of-living increases, and loss of original forest area. The tourism industry is also a major contributor to the generation of greenhouse gases whilst it is accepted that global warming may bring tsunami. Phuket is a high-risk area for tsunami events. This has become more evident since the 2004 Indian Ocean tsunami devastated many coastal areas on the island and this is now a major concern to many citizens. Deforestation is an obvious cause of global warming due to the release of carbon from this pool. As a starting point to find the solution for these stated problems, the study aims to explore the consequence of land-use change on soil carbon stocks in Phuket province from 2000 to 2009, applying geographical information system (GIS). This exploration can help to provide information for Phuket urban planning and initiation of the forest landscape restoration so as to be a part in assisting Phuket's tourism industry to develop sustainably.

1. Introduction

International tourism is a major source of income for Thailand and a forceful developmental drive to circulate money from domestic tourists within the country (MTS, 2015). Phuket is one of the most popular tourist destinations in Thailand. A major source of income for Phuket citizen is tourism. The number of visitors in Phuket in 2013 was around 11.3 M, and income from tourism industry was around 6,912 M USD or approximately 2 % of gross domestic product (GDP) for that year. According to the National Economics and Social Development Board, the province's per capita GPP was at around 7,170 USD. Phuket GPP is the highest among all provinces in the southern region of Thailand, and it holds the 10th position in all of Thailand (PPSO, 2015). The 4th national economic and social development plan (1972-1977) was the key turning point that transformed Phuket from a city with a strategic focus on the mining industry into a focus on the tourism industry. The Phuket provincial development strategy (2015-2019) is currently in use for strengthening the tourism industry by enhancing its international competitiveness (DOT, 2015). There have been significant developments in infrastructure aiming at Phuket's growth (PRED9, 2015). This development has resulted in noticeable changes in land use as that land use is put at the service of the growing demand in the context of global change (DOT, 2015). It is suspected that natural and agricultural areas have been vastly replaced with new buildings and infrastructures such as restaurants, hotels, recreation areas, department stores, sport clubs and roads to reduce traffic congestion.

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Changes in land use is a crucial factor impacting on the greenhouse gas balance (USEPA, 2016). It can result in changes to the amount of carbon storage in soil that can be converted to CO_2 in the air (Erb, 2004), which varies according to geographic factors such as the type of existing vegetation (IPCC, 2006). In the case of either forest or cultivation, if plants have been in existence in the same area, it can be assumed that the carbon stock change in the landscape is zero. If a new type of crop has been replanted in the same area, carbon stock can be increased or decreased (Gnanavelrajah et al., 2008). In response to the changes and conditions stated above, the purpose of this study is to track and analyze land-use changes in Phuket province from 2000 to 2009 by using GIS, and to estimate their impact on soil carbon stocks. This investigation is beneficial to provide visualized information in urban planning and initiation of activities that help reduce risks of climate change such as rehabilitation and restoration of degraded forests (Stanturf et al., 2014). Since the tourism industry is one of the activities resulting in the generation of primary gasses causing climate change (Huang and Tang, 2016); a balance between economic, societal and environmental dimensions for sustainable development must be achieved (Thomé and Scavarda, 2015). This research project aims to make a contribution in supporting effective decision-making to expand Phuket's tourism for socioeconomic growth and to preserve natural areas simultaneously and sustainably.

2. Methodology

2.1 GIS map creation

The secondary land use data were obtained from the Land Development Department, Ministry of Agriculture and Cooperatives of Thailand. Land use and land cover maps in GIS shapefile format of the year 2000 (LU2000) and 2009 (LU2009) were used in the analysis of landscape changes. The land use defined in the maps was classified into three levels corresponding to the Land Development Department. The first level consists of five major types, named Urban and Built-up land, Agricultural land, Forest land, Water Body and Miscellaneous land. There are 60 different types of land use that can be specified in the study area. However, only 11 types of land use were re-grouped and presented to gain a clearer understanding in accordance with the study objectives; they are as follows: U502 (factory), U602 (golf course), U (other urban and built-up land), A1 (paddy field), A (other agricultural land), F1 (evergreen forest), F (other forest), W2 (reservoir 'built-up'), W (other water body), M (miscellaneous land) and NA (non-classify).

Since the LU2000 map was generated based on Indian 1975 datum, it requires coordinate reference system transformation to match with the LU2009 map, which is in the World Geodetic System 1984 (WGS 84) reference. Therefore, the boundary of the study area (the Phuket Island and all small island around it) does not match the same coordinates exactly. The overlap of vector features (polygons) caused by the process of constructing LU2000 map which used the outdated GIS technology and low-resolution satellite images, and the LU2009 were not generated on top of the old LU2000 data. In order to make land-use change analysis more accurate, the LU2000 data required coordinate shifting. The extra pre-processing step was achieved by manually selecting 200 pairs of coordinates around the boundary of Phuket Island that have the same shape (angle or arc) to be the ground reference points from both maps. The different value of latitude and longitude of each pair of selected points were averaged and used as a shifting value for every coordinate of all features in the LU2000 data. This process was done using R program and the coordinate of the polygon features in text format as the input data in order to ensure that the boundary of all vector features from both maps mostly overlay on each other. However, there is some area of polygon (~3 % of all area) around the boundary of the islands that still overlap and this produces the area of non-classify (NA) in the land use change analysis process. Both land use data were converted from vector to raster with 100 by 100 meter grid resolution using maximum combined area algorithm. Grid analysis was then used to analysis and extract change of LU2000 and LU2009 using QGIS software.

2.2 Estimation of carbon storage in the soil

This study uses standard guidelines (IPCC, 2006) with local data to estimate how much carbon is stored and emitted to the atmosphere from the changes in land use in Phuket. The change of carbon storage can be estimated using the following equation:

$$SOC = SOCREF \times FLU \times FM_G \times FI \times A \times 100 \quad (1)$$

The term SOC is soil carbon stock in managed land (unit: T C); SOCREF is the reference carbon stock (unit: T C hectare^{-1}), FLU is stock change factor for land-use systems (dimensionless), FM_G is stock change factor for management regime (dimensionless), FI is stock change factor for input of organic matter (dimensionless), and A is land area (unit: hectare). The calculation unit for the estimation of carbon storage in soil for each type of forest located in Phuket area are shown in Table 1. It can be assumed that urban areas such as factories, airports, villages, buildings, and roads, have no carbon stored in their surface soil (Dorendorf, 2014). That is the reason why there are only 5 land categories, i.e., paddy field, other agricultural land, evergreen forest (tropical rain forest), dense deciduous forest and mangrove forest) presented in Table 1.

Table 1: Estimation of aboveground carbon stock per hectare for each type of forest in tropical wet

Land categories	Reference carbon stock	Stock change factor for			Carbon stock per hectare	Reference
		land-use systems	management regime	input of organic matter		
Paddy field	60	1.1	1.22	1.11	89.38	IPCC, 2006
Other agricultural land	60	1	1.22	1.11	81.25	IPCC, 2006
Evergreen forest: tropical rain forest	-	-	-	-	125.5	THAI-GLOB, 2011
Dense deciduous forest	-	-	-	-	40.5	THAI-GLOB, 2011
Mangrove forest	-	-	-	-	82.6 (primary) 35.2 (secondary)	THAI-GLOB, 2011

3. Results and discussion

3.1 Land-use change and categories

Phuket has an area of 542.7 km^2. Its shape and land utilizations in 2000 and 2009 were illustrated in Figure 1. Land-use change matrices for Phuket, Thailand between 2000 and 2009 were constructed for a simplified set of 11 land-use categories as presented in Table 2. According to the inventory in 2000, other agricultural land, evergreen forest, and other urban & built-up land were the main areas of land use for a total of 292.9, 96.6, and 80.4 km^2 while that in 2009, other agricultural land, other urban & built-up land, and evergreen forest were the main areas of land use at 228.8, 119.6, and 92.4 km^2, respectively. These numbers show the substantial increase of city area and decrease of farmland during that 10 year periods, mainly in the southern part of the island as demonstrated in Figure 1.

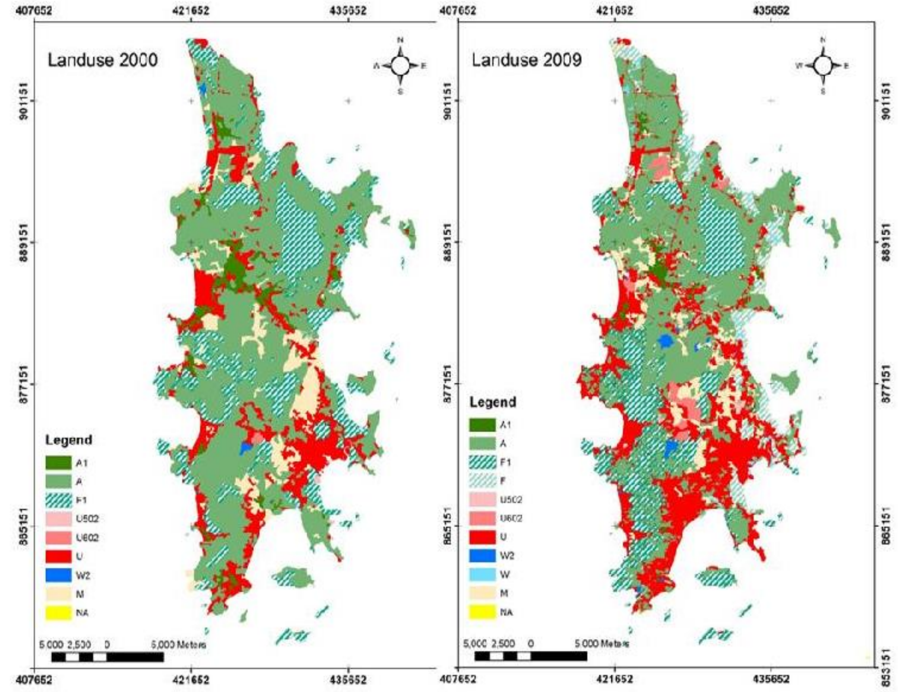

Figure 1: Phuket's land use 2000 (left) and 2009 (right)

The amount of factory area increased by 1.6 km^2, raising from 0.5 to 2.1 km^2, while factories were all moved to new locations. To serve the tourists' demand, golf courses in Phuket area increased by more than 13 times from 0.7 to 9.5 km^2 (located on the area of other agricultural land and other urban & built-up land in 2000). Rice fields decreased almost 3 times and most of them have become other urban & built-up land. The amount of other agricultural land decreased from 292.9 to 228.75 km^2 while that of other urban & built-up land increased from 80.4 to 119.6 km^2. These numbers imply a change in the social structure going from agricultural human activity to urban city human activity.

Nevertheless, the amount of evergreen forest area decreased only ~4 km^2, falling from 96.5 in 2000 to 92.4 km^2 in 2009, while other forest area had an area of 35.5 km^2 in 2009. The reason behind the increase of total forest area, even almost 30 km^2 of forestland in 2000 changed to nonforest in 2009, was due to the largest transformation of area (~42 km^2), from other agricultural land into evergreen forest. Most of this transformed area were located in the land-reform area. Thai government initiated the land-reform scheme, in 1975, in order to distribute degraded forest areas to poor farmers under the condition for temporary land tenure, so-called S.P.K.4-01 (Sor Por Kor 4-01). The landowners and inheritors holding this certificate could utilize the land for only agricultural propose (Wannasai and Shrestha, 2008). However, in practice, not all of the distributed lands were used for agriculture because a considerable part of them were not worth and suitable for cultivation (e.g., too steep, difficult to access). Thus, some areas remained uncultivated and turned naturally into dense forest under local owners' responsibility to protect and safeguard the areas from invasions for any usages inconsistent with the original purpose of the land-reform program. Regarding type of forest in Phuket, apart from evergreen forest, other forest area consisted of dense mangrove forest, disturbed mangrove forest, and dense deciduous forest which were estimated to be around 28, 2 and 5 km^2, respectively. Actually, a large part of other forest area in 2009 (22.2 km^2) were evergreen forest in 2000 but it was not specifically categorized in the LU2000 data. Reservoir 'built-up' increased approximately 3 times. This indicates awareness of high water consumption and good planning urbanization during 10 years from 2000 to 2009.

Table 2: Land-use change matrix for Phuket between 2000 and 2009 (unit: km^2); U502: factory, U602: golf course, U: other urban & built-up land, A1: paddy field, A: other agricultural land, F1: evergreen forest, F: other forest, W2: reservoir 'built-up', W: other water body, M: miscellaneous land and NA: non-classify (same abbreviation and full term for Figure 1)

Land use 2000	Land use 2009											
	U502	U602	U	A1	A	F1	F	W2	W	M	NA	Total
U502	0	0	0.43	0	0.02	0	0.03	0.0	0	0	0.01	0.49
U602	0	0.63	0	0	0	0.09	0	0	0	0	0.00	0.72
U	0.53	3.08	57.59	0.79	9.29	1.09	1.45	0.48	0.44	5.11	0.55	80.40
A1	0.10	0	6.58	5.26	2.98	0.03	0.04	0.07	0.01	3.72	0	18.79
A	0.75	5.40	32.36	0.65	190.31	42.49	6.75	1.54	0.28	10.47	1.91	292.91
F1	0	0.37	6.07	0.01	17.48	45.90	22.21	0.04	0.60	2.18	1.69	96.55
W2	0	0	0.03	0	0.25	0.10	0	0.50	0.26	0	0	1.14
M	0.73	0.05	13.13	0.03	7.17	1.96	1.29	0.60	0.41	13.80	0.73	39.90
NA	0	0	3.44	0	1.25	0.77	3.68	0.0	1.33	1.3	0	11.80
Total	2.11	9.53	119.63	6.74	228.75	92.43	35.45	3.24	3.33	36.60	4.89	542.70

3.2 Carbon storage and its change from 2000 to 2009

Using the information from Table 1 and 2, carbon stocks from land-use change in Phuket is estimated and presented in Table 3. There are 2 columns for carbon stock in 2009. One (2009A) is for the fair comparison with carbon stock in 2000 by using the same forest categories since dense deciduous forest and mangrove forest were still identified as 'evergreen forest' in the LU2000 data. The other one (2009B) is for giving more accurate values of carbon stock according to the updated data. Though using the values of carbon stock in 2009A give the higher values of that in 2009B, overall, losses of carbon were found for both cases compared to 2000. The losses in carbon stocks in 2009A and 2009B compared to 2000 were 242 and 307 T carbon, approximately. In conclusion, changing the land-use from agricultural area to other land-use categories is a major cause of carbon release from the soil surface for this study area.

Table 3: Carbon stock in soil: 2000, 2009A and 2009B (unit: T)

Land categories	Carbon stock			Carbon stock change	
	2000	2009A	2009B	A*	B**
Paddy field	167.9	60.2	60.2	-107.7	-107.7
Other agricultural land	2379.9	1858.6	1858.6	-521.3	-521.3
Evergreen forest	1211.7	1599.2***	1160.0	387.5	-51.7
Dense deciduous forest	0	0	20.3	0	20.3
Mangrove forest	0	0	353.4	0	353.4
Others	0	0	0	0	0
Total	3759.5	3518.1	3452.5	-241.5	-307.1

*Carbon stock change A = carbon stock in year 2009A - carbon stock in 2000
**Carbon stock change A = carbon stock in year 2009B - carbon stock in 2000
***dense deciduous forest and mangrove forest were calculated by using the same factor as evergreen forest

4. Conclusions

This study uses the implementation of GIS integrated with the technique for estimating carbon storage in the soil. GIS data is applied for the investigation of land use for years 2000 through 2009 in Phuket Island, a popular destination for both Thai and foreign travellers. The results illustrate the changes in land use due to the national development plan focusing on tourism. This, in turn, resulted in changes to the social structure from agrarian society to urban society. The GIS data and findings from the literature indicate that there has been an effort to secure green areas in Phuket at the same time that it has been transformed into a major tourism hub. Even the amount of forest areas in 2009 was larger than that in 2000, the results show that effort alone is not enough to maintain the quantity of carbon stock in the soil to ensure effective action against global warming. This is due to the significant transformation of agricultural areas into other urban categories as a result of citizen's adaptation along with the promotion of tourism. Moreover, according to the current provincial development strategy (DOT, 2015), there is not only a decrease of agricultural area, but it is a difficult and challenging task to avoid a decrease of forest area due to the expansion of the tourism industry in the near future. As explained above, this degradation of the natural and agricultural environment can have negative effects including climate change, a possible cause of tsunami (Kain et al., 2015). Consequently, a revision of development strategy or effective mitigation plans must be urgently triggered not only to retain but also to ensure an increase of green areas at the provincial and national levels.
Further research with an aim for finding a comprehensive solution to support decision-making process for sustainability of Phuket's tourism including socioeconomic dimension is necessary. The next step will be the application of the latest GIS data integration with satellite imagery for obtaining the most updated land-use situation. Not only to estimate the amount of carbon stored in and emitted from surface soil, GIS can also be applied as a tool to evaluate hotspots of emissions that are produced from human activities such as transport, industry and so on (Asdrubali et al., 2013). Developing emissions inventory and finding air pollution hotspots in Phuket area by using GIS for helping decision makers in choosing the proper management strategies (Pozza et al., 2015) and any available techniques that can reduce GHG emissions (Ishak et al., 2015) has been started and ongoing.

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APPENDIX B

Publication II

Inventory of Greenhouse Gas Emissions for Phayao Province – An Agricultural City in Thailand

163

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Inventory of Greenhouse Gas Emissions for Phayao Province - An Agricultural City in Thailand

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Greenhouse gas (GHG) mitigation is one of the major challenges that all countries face. The impacts of GHG emissions cost people and ecosystem everywhere. Hence, it is the responsibility of all parties to tackle this serious problem. For instance, Thailand has agreed to decrease GHG emissions by 20 % from the projected business-as-usual (BAU) level by 2030 despite no commitment to target GHG emissions reduction. As a part of the contribution, this study aimed at preparing a GHG emissions inventory (EI) from the main pollution sources in Phayao province located in the North of Thailand. We investigated annual amount of GHG emissions by using a bottom-up approach. Both primary data from field survey and secondary data from governmental agencies in Thailand were employed in our analysis. From the preliminary study, Phayao's economy depends on agriculture, like other ASEAN countries. The major sources of GHG generation comprised of rice cultivation, open burning (including crop residue burning and forest fire), road transportation, industry, and livestock (from enteric fermentation and manure management). GHG emissions from rice fields, open burning, road transportation, industry, and livestock were estimated to be 773,325; 1,819,225; 195,497; 4,625 and 133,830 t CO_2-eq. Approximately 89 % of GHG emissions were emitted from agricultural sector (biomass open burning and rice cultivation). The results of this study suggest that the proper and effective measures for mitigating GHG emissions from agricultural ecosystems is the first priority to emphasise.

1. Introduction

Ocean and land temperatures demonstrate that the Earth has been warmed. This phenomenon is attributed to human-caused GHG emissions. The average global, land, and ocean temperature has now risen about 0.7, 1, and 0.6 °C above normal in the last 100 years (Prasad et al., 2017). Geographically, Thailand is one of the sixteen countries at extreme risk due to climate change impacts over the next thirty years with a higher growth rate of average temperature compared to the world (an increase of ~ 1 °C within ~ 50 years) (ONEP, 2015b). Also, Thailand is one of the seven countries in the Asia with high population, a major factor that can make things difficult for the protection of environment (Klemeš et al., 2017). Anyway, Thailand has committed to a voluntary 7 % - 20 % GHG reduction in the energy and transport sectors by 2020 and 20 % reduction from the projected BAU level (~ 555 Mt CO_2-eq) by 2030 (Leggett, 2015). Thailand is an agricultural country (Arunrat et al., 2016), same as most of the ASEAN countries (except Singapore and Brunei) (Shukun and Yanhua, 2014). Agriculture is the 2nd largest contributor to GHG emissions after energy sector (Bordoff, 2016) and this makes it a major source of GHGs emitted to the air from ASEAN. This should be the same with Phayao province, an agricultural city with an estimated population of 0.49 M in 2013 (NSO, 2013) that obtained 422 M USD or 43 % of gross provincial product from agricultural activities (NESDB, 2013). That income was created from ~ 228,920 ha of arable land, accounting for 36.1 % of the whole territory. Rice is the most important crop occupying ~ 132,798

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ha (58 %) of the total cultivated area in Phayao (Pimmasarn et al., 2013). Other economic crops (e.g., corn, longan, lychee, garlic, and shallot) occupy space less than 10 % of the provincial area (OAE, 2015). Apart from agricultural sector, from the preliminary observation, forest fire, transportation, industry and livestock can also be the main contributors to global warming potential (GWP) in this province. So as to meet the goal to reduce GHG emissions efficiently and cost-effectively, an initial task is to identify environmental hotspots. This study aims to develop a GHG EI for Phayao province, a northern city in Thailand, by using bottom-up approach that takes a detailed look at each potential source in an investigation (Song et al., 2017).

2. Methods

2.1 Activity data

Detailed data for the estimation and development of a GHG EI for Phayao province were obtained from many sources including governmental organisations. The summary of activity data and sources of information are presented in Table 1. Major sources of emissions based upon data availability can be categorised as rice field, open burning, transport, industry, and livestock. Aside from on-site data collection, related information for the estimation of GHGs for paddy field was mainly acquired from Phayao Provincial Agricultural Extension Office (DOAE, 2011). The emission factor (EF) values for rice field were adopted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). To estimate emissions from open burning of all main agricultural residues and forest fire, high-resolution satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS) were utilised to identify the location and size of the burn (NASA, 2012). The EF values from literatures for crop residue burning (rice, and corn) (Kanabkaew and Oanh, 2011) and forest fire were used (Andreae and Merlet, 2001). Actually, forest fire (with or without intention) is a cause of land-use change, a crucial factor that impact on GHG balance (Prueksakorn, 2017). To develop a GHG EI for transport section of Phayao province, data for traffic, car speed, registered car, and fuel amount were obtained from Department of Highway (DOH, 2012), Highway Police Division (HPD, 2012), Department of Land Transport (DLT, 2012), and Ministry of Energy (MOE, 2015). Traffic data observed by DOH was collected from 7.00 am – 7.00 pm, and data for the remaining time to complete the 24 h sampling was further collected on site, manually. The EF values for transport were determined based on fuel used, year of cars, and type of cars, from the research project studied in Bangkok, Thailand (ESMAP, 2009). For industries, the activity data were partly received from Phayao Province Industry Office (PIO, 2012). Additional survey was performed to complete activity data. The values of EF were extracted from the guideline of United States Environmental Protection Agency (US EPA, 2005). The data for livestock were collected from provincial livestock office and site survey (Muenchan and Pimonsree, 2012). The EF values for livestock were derived from the IPCC (IPCC, 2006).

Table 1: The activity data from major sources of GHGs generation in Phayao

Emission sources	Related data for the estimation	The source of data
Rice cultivation	Registered farmer, area,	DOAE, 2011
	plantation method	Pimmasarn et al., 2013
Open burning	Hotspot	NASA, 2012
Transportation	Traffic	DOH, 2012
	Speed of car	HPD, 2012
	Registered car	DLT, 2012
	Fuel	MOE, 2015
Industry	Location, production capacity,	PIO, 2012
Livestock	Pollution control technology, animals,	Muenchan and Pimonsree, 2012
	farm locations, sex, and weight	

2.2 Emissions Estimation

To estimate GHG emissions in the study period, carbon assessment manual 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories is used in this study. GHG substances i.e., CO_2, CH_4, and N_2O are then converted to the single unit – CO_2 equivalent (CO_2-eq) for 100 years with the conversion factors based on IPCC (2006); 1 time for CO_2, 25 times for CH_4, and 298 times for N_2O.

2.2.1 Rice cultivation

The emissions for rice cultivation are estimated by using Eq(1) (IPCC, 2006).

$$E = EF \cdot t \cdot A \qquad (1)$$

where E is the amount of CH_4 emissions from rice cultivation (t CH_4), EF is emission factor (t CH_4 ha^{-1} day^{-1}), A is the cultivation area of rice field (ha), and t is the cultivation period of rice field (day).

2.2.2 Biomass burning

The emissions for biomass open burning are estimated by using the following Eq(2) and Eq(3).

$$E = M \cdot EF \quad (2)$$

where E is quantities of CO_2 or CH_4 emissions from burning (t CO_2 or t CH_4 respectively), M is the quantities of biomass burning ($kg_{dry\ mass}$), EF is emission factor from different biomass crops (t CO_2 or t $CH_4 \cdot kg_{dry\ mass}^{-1}$). Two methods are applied to determine the amount of biomass (M). Biomass burning at the forest area was calculated by using Eq(3) and biomass burning at the agriculture area was calculated by using Eq(4).

$$M = A \cdot B \cdot C \quad (3)$$

where A is the burned area (km^2), B is the biomass density in the forest area ($kg_{dry\ biomass} \cdot km^{-2}$), and C is burning efficiency.

$$M = P \cdot N \cdot D \cdot \beta \cdot F \quad (4)$$

where P is crop production (kg), N is the residue to crop ratio, D is dry matter to crop residue ratio, β is the fraction burned in the field, and F is the crop specific burn efficiency ratio (IPCC, 2006).

2.2.3 Transportation

The estimation for emissions generated from transport was done using Eq(5).

$$E = A \cdot EF \quad (5)$$

where E is quantifies of CO_2 emissions from transportation (t CO_2), A is activity data (km) of emission source, and EF is the emission factor (t $CO_2 \cdot km^{-1}$). Activity data for this sector can be calculated using Eq(6).

$$A = \sum [(N \cdot Y \cdot F) \cdot distance] \quad (6)$$

where N is the number of car, Y is the proportion of car, and F is the fraction of car (IPCC, 2006).

2.2.4 Industry

The emissions for industry is calculated by using Eq(7).

$$E = A \cdot EF \cdot \left(\frac{1 - ER}{100}\right) \quad (7)$$

where E is the quantities of CO_2 emissions from industry (t CO_2), A is activity data (Mg), EF is emission factor (t $CO_2 \cdot Mg^{-1}$), and ER is overall emission reduction efficiency (%) (US EPA, 2005).

2.2.5 Livestock

The emissions from livestock can be mainly caused by two activities consisting of enteric fermentation and manure management estimated by using Eq(8) and Eq(9) respectively (IPCC, 2006).

$$E = EF_{(T)} \cdot [N_{(T)}] \quad (8)$$

where E is quantities of CH_4 emissions from enteric fermentation and manure management (t CH_4), $EF_{(T)}$ is emission factor for the defined livestock population (t CH_4 $head^{-1}$), and $N_{(T)}$ is the number of livestock (while T is the category of livestock).

$$N_2O_D = \left[\sum_S \left[\sum_T (N_{(T)} \times Nex_{(T)} \times MS_{(T,S)})\right] \times EF_{3(S)}\right] \times \frac{44}{28} \quad (9)$$

where N_2O_D is direct N_2O emissions from manure management (tCO_2-eq), S is manure management system, T is division of livestock, N(T) is the number of head of each category of livestock T, $Nex_{(T)}$ is average N excretion per head of each category of livestock T (kg N $animal^{-1}$), $MS_{(T,S)}$ is the fraction of total annual nitrogen excretion for each category of livestock T that is managed in manure management system S, $EF_{3(S)}$ is emission factor for direct N_2O emissions from manure management system S (t N_2O-N kg N^{-1}), 44/28 is the conversion factor which is converted from N_2O-N emissions to N_2O emissions.

3. Results and discussion

3.1 GHG emissions in Phayao province

Within the scope of study, the total annual GHGs emitted from rice field, biomass burning, transportation, industry, and livestock were 2.9 Mt CO_2-eq (Table 2). GHG emissions were mostly contributed by biomass open burning (1,819,225 tCO_2-eq, 62 % of the total) even though the investigation includes only rice and corn. Other minor crops were omitted due to unavailability of data but it should be acceptable with the similarity to China's case that rice and corn were the major sources (90 %) of air pollutions from all kinds of crop residues (Huang et al., 2012). Apart from biomass burning, GHG emissions can also be produced during the cultivation process (Arunrat et al., 2016), especially CH_4 from rice field (Guo et al. 2017). This also corresponds to the study result in Vietnam (Delafield, 2015) that agriculture is the biggest contributor to GHG production. GHGs from other major processes were emitted with the following shares: 6.7 % from transportation, 0.2 % from industry, and 4.6 % from livestock.

Table 2: GHG emission (t y^{-1}) generated from major sources in Phayao

Emission sources	CO_2	CO_2-eq	CH_4	CO_2-eq	N_2O	CO_2-eq	Total CO_2-eq
Rice field			30,933	773,325			773,325
Open burning	1,675,050	1,675,050	5,767	144,175			1,819,225
Transportation	195,497	195,497					195,497
Industry	4,625	4,625					4,625
Livestock			4,371.2	109,280	82.4	24,555	133,830
Total	1,875,172	1,875,172	41,071.2	1,026,780	82.4	24,555	2,926,502

3.2 Comparison with other cases in ASEAN

Benchmarks for the verification and interpretation of GHG emissions generated in Phayao province are presented in Table 3, mainly from case studies in ASEAN countries.

Table 3: Comparisons with studies in ASEAN

Emission Sources	Region & References	Area (ha)	Population (Persons)	CO_2-eq from CO_2	CO_2-eq from CH_4	CO_2-eq from N_2O
Rice field	This study	228,920			3.4	
	Vietnam (Torbick et al., 2017)	1,078,783			10.7	
Biomass burning	This study			7.3	0.6	
	Phichit (Arunrat et al., 2016)					
	Rice residue for irrigated area			2.1[a]		
	Rice residue for rainfed area			3.0[a]		
Transportation	This study	6,335	0.49×10^6	1.1[a]		
	Malaysia (Ong et al., 2011)	329,750	1.76×10^6	2.5	0.02	0.03
	Brunei (Dotse et al., 2016)	5,765	0.39×10^6	4.2	0.01	0.08
Industry	This study			4,625[a]		
	Thailand (ONEP, 2015a)			18.2×10^6 [a]		
Livestock	This study				109,280	24,555
	Philippines (Lingad et al., 2014)			26,018[a]		

[a] from all GHGs (CO_2, CH_4 and N_2O)

Note: All units for rice field are in t CO_2-eq ha^{-1} y^{-1}, for biomass burning are in t CO_2-eq ha^{-1} y^{-1}, for road transportation are in t CO_2-eq $vehicle^{-1}$ y^{-1} from industry are in t CO_2-eq y^{1}, and from livestock are in t CO_2-eq y^{-1}

For the comparison of GHGs emitted from rice field, the case of Vietnam is chosen (Torbick et al., 2017). The gap of values is about 3 times (per plantation area) which is possible due to the difference of estimation techniques. The data collected in this study is based on bottom up approach while the data in Vietnam's case is based on satellite remote sensing. Further comparison using the same approach is important. The case of Phichit province, Thailand (Arunrat et al., 2016) was chosen for the comparison of GHGs emitted from biomass burning. The gap of values (5 to 7 times) is a lot larger than that of cultivation. This is because the GHGs value presented in this study is for overall biomass while in the Phichit's case is only for rice straw. Forest fire has the highest rate of emitting GHGs per weight compared to all other types of biomass especially since the forest fire from this study is in the tropical zone (high-density) (Permadi et al, 2013). Comparing by type (forest and agricultural biomass) is highly necessary for the distinction. For the comparison of transportation sector, the cases of Malaysia (Ong et al., 2011) and Brunei (Dotse et al., 2016) are selected. The number of vehicle of this study, Malaysia's case, and Brunei's case are 193,374, 16,813,943, and 399,800. GHGs emitted from transportation sector in Malaysia and Brunei's cases are around 2 and 4 times higher compared to the results from this study. The gaps of values are not low, but they are in possible ranges. The shortest reason to explain about this difference is the higher gross domestic product (GDP), implying more activities of the country, possibly causing more traffic density. GDP of Thailand is usually >20 % lower than that of Malaysia and Brunei (US-ASEAN, 2016). A lot more accurate analysis and explanation can be obtained if road distance, study size, vehicle type, vehicle year, fuel type, and fuel consumption are interpreted. Most of GHG emissions are produced by fossil fuels generated from transportation as stated by Lee et al. (2017), it constitutes 20 % of 2013 total world CO_2 emissions. For industrial sector, due to the variety of industrial types with the varieties of energy type and chemicals used, it is not easy to find a fair comparison. GHGs values are presented in terms of the ratio with its national number, which is 2.5 x 10^{-4}. This low fraction implies that industry is a small economic sector in this agricultural province. For the last sector – livestock, it is compared with Salikneta farm – Philippines' case. The number of animals for this study and Philippines' case are 19,275 and 726 heads. The gap of GHG values is about 194 times (6.9 and 0.04 t CO_2-eq per head for this study and Philippines' case). The reason of this big gap is the animal type, especially for cow – the major contributor to GWP (Lingad et al., 2014). The number of cow for this study and Philippines' case are 747 and 6 heads (124.5 times – close value to the gap of GHGs). Even this is not a fair comparison either, this analysis emphasises the significant release of GHGs from cow.

4. Conclusions

This paper focuses on illustrating GHG emissions from rice cultivation, biomass burning, road transportation, industry and livestock – considered as major contributors in Phayao Province, Thailand – from 2012 - 2013. Almost 90 % of GHG emissions were emitted from agricultural sector (biomass open burning and paddy cultivation) even though the data in this part are incomplete compared to other sectors. From this study, the initial and most effective mitigation should be the control of open burning which is the biggest contributor to GWP. If the control is successful, the side benefit is to control smog problem that is a serious environmental problem in ASEAN. The verification of investigation is also performed but due to space constraint, more data and analysis are necessary for the comprehensive explanation and reliability before any further mitigation is initiated.

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APPENDIX C

The Data of Land Use in Phuket province

Table C.1 The data of land use in Phuket province in 2007 (LDD, 2016)

Land use name	Area (ha)
Abandoned Aquaculture land	16.4
Abandoned mine, pit	2,645.7
Abandoned paddy field	531.0
Agricultural product trading centers	5.8
Airport	177.8
Beach	0.5
Casuarina	9.4
Cemetery	2.6
City, town, commercial	1,282.5
Coconut	1,822.5
Dense deciduous forest	524.0
Dense evergreen forest	9,592.5
Dense mangrove forest	2,932.9
Disturbed mangrove forest	147.4
Factory	143.1
Farm pond	88.7
Fish farm	17.7
Golf course	578.8
Grass	913.1
Harbor	99.7
Institutional land	371.5
Lake	158.7
Mine	251.4
Mixed orchard	44.3
Mixed orchard/Coconut	6.1

Table C.1 The data of land use in Phuket province in 2007 (Continued)

Land use name	Area (ha)
Mixed perennial	19.8
Oil palm	234.7
Para rubber	20,149.2
Poultry farm house	15.7
Recreation area	3,088.1
Reservoir	144.0
Rice paddy	327.3
River and canal	247.3
Road	440.5
Scrub	768.1
Soil pit	5.7
Truck crop	36.8
Village	4,191.4
Village/Coconut	264.9
Village/Mixed orchard	211.8

Table C.2 The data of land use in Phuket province in 2009 (LDD, 2016)

Land use name	Area (ha)
Agricultural product trading centers	5.8
Airport	189.8
Beach	183.7
Cashew	4.3
Cemetery	2.6
City, town, commercial	1,286.4
Coconut	1,719.2
Dense deciduous forest	9,738.3
Dense mangrove forest	2,875.0

Table C.2 The data of land use in Phuket province in 2009 (Continued)

Land use name	Area (ha)
Disturbed mangrove forest	139.2
Durian/Mangos teen	12.0
Factory	209.8
Farm pond	100.5
Fish farm	11.7
Floricultural	2.1
Golf course	942.0
Grass	812.0
Harbor	99.7
Institutional land	407.3
Lake	147.4
Landfill	49.1
Laterite pit	7.0
Marsh and Swamp	30.2
Mine	32.2
Mixed orchard	60.3
Mixed orchard/Coconut	6.1
Mixed perennial	19.8
Oil palm	149.9
Para rubber	19,739.6
Pineapple	1.5
Pineapple/Para rubber	25.6
Poultry farm house	15.7
Rambutan	1.1
Recreation area	147.1
Reservoir	267.2
Rice paddy	235.7
River and canal	269.1

Table C.2 The data of land use in Phuket province in 2009 (Continued)

Land use name	Area (ha)
Road	447.8
Scrub	729.5
Shrimp farm	867.5
Soil pit	5.7
Sweet potato	0.4
Swine farm house	10.4
Teak	1.4
Truck crop	38.7
Village	9,066.0
Village/Coconut	205.0
Village/Mixed orchard	210.2

Table C.3 Stock change factor for each type of land use in Phuket province

Land use types	Reference carbon stock	Stock change factor			Carbon stock / ha
		F_{LU}	F_{MG}	F_3	
Mangrove forest	-	-	-	-	122.19[a]
Evergreen forest	-	-	-	-	238.00[a]
Deciduous forest	-	-	-	-	172.00[a]
Paddy field	-	-	-	-	10.00[a]
Corn	-	-	-	-	-
Rubber	-	-	-	-	66.00[a]
Coconut	-	-	-	-	44.17[b]
Longan	-	-	-	-	-
Golf course	-	-	-	-	30.4[c]
Grassland	-	-	-	-	66.3[d]

Note: [a], [b], [c], [d] refer to source of information; a: Arunyawat and Shrestha, 2016; b: Ranasinghe and Thimothias, 2012; c: Kong *et al.*, 2014; and d: MRC, 2017.

APPENDIX D

The Data of Land Use in Phayao province

Table D.1 The data of land use in Phayao province in 2007 (LDD, 2016)

Land use name	Area (ha)
Abandoned aquaculture land	7.9
Abandoned area	3.3
Abandoned factory	11.6
Abandoned field crop	147.2
Abandoned mine, pit	66.6
Abandoned paddy field	263.4
Abandoned village	0.5
Abandoned farm house	1.5
Actifed paddy field	118,153.1
Agricultural product trading centers	40.6
Baboo	26.3
Bamboo	15.1
Banana	7.1
Banana/Longan	2.2
Bush fallow	682.8
Bush fallow/Corn (Swidden cultivation)	1.3
Bush fallow/Mixed field crop (Swidden cultivation)	59.3
Cashew	1.0
Cassava	8.9
Cattle farm house	13.5
Cemetery	230.3
Cerlera sp.	2.3
City, town, commercial	3,884.5
Coconut	3.1

Table D.1 The data of land use in Phayao province in 2007 (Continued)

Land use name	Area (ha)
Coconut/Longan	0.7
Corn	47,021.4
Corn(Swidden cultivation)	4,798.4
Corn(Swidden cultivation)/Un-land rice(Swidden cultivation)	1,715.5
Corn/Cassava	20.0
Corn/Longan	3.5
Corn/Tobacco	49.7
Corn/Truck crop	3,271.2
Corn/Upland rice	13,286.6
Dense deciduous forest	255,971.6
Dense evergreen forest	81,314.0
Dense forest plantation	1,070.5
Disturbed deciduous forest	13,368.8
Disturbed evergreen forest	677.1
Disturbed forest plantation	25.9
Dragon fruit	5.9
Eucalyptus	167.8
Eucalyptus/Teak	1.2
Factory	383.1
Farm pond	628.4
Fish farm/Longan	2.4
Floricultural/Ornamental plant	0.3
Garbage dump	14.8
Gasoline station	14.4
Goff course	2.1
Grass	1,105.3
Guava	2.6

Table D.1 The data of land use in Phayao province in 2007 (Continued)

Land use name	Area (ha)
Hill tribe village	101.0
Irrigation canal	33.9
Jack fruit	2.3
Lame	0.3
Landfill	56.8
Laterite pit	113.3
Litchi	4,307.2
Litchi/Longan	267.2
Litchi/Mango	9.7
Longan	13,831.8
Longan/jack fruit	5.4
Magosa	10.0
Mango	436.9
Mango/Longan	69.3
Mango/Tamarind	54.3
Marsh and Swamp	3,837.8
Marsh and Swamp+Actived paddy field	683.0
Marsh and Swamp+Corn	3,232.7
Mine	315.3
Mixed field crop	1,314.2
Mixed orange	560.1
Mixed perennial	33.9
Mulberry	3.1
Mung bean	0.9
Natural water resource	3,074.6
Orange	19.5
Orange/Longan	2.0
Orange/Mango	6.4

Table D.1 The data of land use in Phayao province in 2007 (Continued)

Land use name	Area (ha)
Orange/Rambutan	1.8
Orange/Tamarind	2.2
Papaya	0.8
Para rubber	2,510.4
Para rubber/Longan	9.4
Para rubber/Tamarind	1.6
Pasture	31.7
Pineapple	45.7
Pomelo	29.1
Poultry farm house	5.4
Poultry farm house/Fish farm	5.3
Pterocarpus sp.	2.7
Rain tree	126.5
Rambutan	2.1
Rambutan/Litchi	0.8
Recreation area	50.4
Reservoir	2,904.9
Resort, hotel, guesthouse	11.2
River, canal	1,640.1
Road	214.1
Rock out crop	221.5
Santon	5.4
Scrub	7,389.7
Shrimp farm	7.8
Soil pit	29.5
Sugarcane	17.3
Swine farm house	2.6
Swine farm house/Fish farm	11.0

Table D.1 The data of land use in Phayao province in 2007 (Continued)

Land use name	Area (ha)
Tamarind	902.8
Tamarind/Longan	127.1
Tea	0.4
Teak	2,693.3
Teak/Longan	2.1
Teak/Mango	1.4
Teak/Pterocarpus sp.	4.5
Thai village	14,105.9
Tobacco	99.2
Truck crop	263.6
Truck crop/Fish farm	1.4
Un-land rice(Swidden cultivation)	37.5
Upland rice	183.5

Table D.2 The data of land use in Phayao province in 2009 (LDD, 2016)

Land use name	Area (ha)
Abandoned area	2.9
Abandoned factory	10.0
Abandoned field crop	25,488.0
Abandoned mine, pit	65.4
Abandoned paddy field	211.2
Abandoned village	0.5
Acacia	2,433.0
Activated paddy field	102,336.4
Activated paddy field + Corn	978.0

Table D.2 The data of land use in Phayao province in 2009 (Continued)

Land use name	Area (ha)
Agalloch	2,361.0
Agalloch/Longan	266.0
Agalloch/Orange	167.0
Bamboo	18,952.0
Bamboo	26.0
Banana	20,966.0
Banana/Longan	3,350.0
Banana/Pomelo	108.0
Banana/Tamarind	382.0
Cashew	102.0
Cassava	47,331.0
Cemetery	222.9
Cerlera sp.	386.0
Chili	469.0
City, town, commercial	3,460.0
Coconut	2,825.0
Coconut/Longan	648.0
Coffee	1,513.0
Corn	1,058,299.0
Corn/Cassava	1,407.0
Corn/Cotton	4,455.0
Corn/Longan	351.0
Corn/Mung bean	210.0
Corn/Para rubber	821.0
Corn/Sorghum	108.0
Corn/Tobacco	5,531.0
Corn/Truck crop	194,090.0
Corn/Upland rice	584,164.0

Table D.2 The data of land use in Phayao province in 2009 (Continued)

Land use name	Area (ha)
Cotton	11,373.0
Custard apple	556.0
Custard apple/Longan	523.0
Disturbed deciduous forest	271,390.5
Disturbed evergreen forest	74,983.4
Eucalyptus	43,969.0
Eucalyptus/Bamboo	155.0
Eucalyptus/Longan	221.0
Eucalyptus/Teak	472.0
Factory	400.7
Farm pond	618.4
Garbage dump	13.2
Gasoline Station	12.6
Ginger	541.0
Golf course	2.1×10^{-6}
Grass	1,078.4
Hill tribe village	108.0
Indian mahogany	2,030.0
Indian mahogany/Mango	256.0
Institutional land	2,974.6
Integrated farm/Diversified farm	27,127.0
Irrigation canal	35.0
Landfill	58.2
Laterite pit	114.1
Litchi	120,742.0
Litchi/Mango	13,577.0
Litchi/Pomelo	106.0
Litchi/Santol	154.0

Table D.2 The data of land use in Phayao province in 2009 (Continued)

Land use name	Area (ha)
Longan	1,833,533.0
Magosa	1,137.0
Magosa/Teak	593.0
Mango	65,856.0
Mango/Banana	424.0
Mango/Longan	13,029.0
Mango/Tamarind	9,153.0
Marsh and Swamp	3,724.2
Marsh and Swamp + Activated paddy field	716.8
Marsh and Swamp + Corn	3,265.6
Mine	333.6
Mixed field crop	7,938.0
Mixed orchard	50,113.0
Mulberry	2,301.0
Mung bean	8,803.0
Natural water resource	3,208.8
New Guinea labula	2,352.0
Oil palm	1,374.0
Orange	9,756.0
Orange/Longan	201.0
Orange/Mango	634.0
Orange/Rambutan	184.0
Orange/Tamarind	215.0
Paddy field	947,045.0
Para rubber	631,419.0
Para rubber/Banana	1,304.0
Para rubber/Litchi	725.0

Table D.2 The data of land use in Phayao province in 2009 (Continued)

Land use name	Area (ha)
Para rubber/Longan	22,939.0
Para rubber/Mango	315.0
Para rubber/Mixed orchard	106.0
Para rubber/Pomelo	168.0
Para rubber/Tamarind	1,049.0
Para rubber/Teak	525.0
Pineapple	4,071.0
Potato	781.0
Pterocarpus sp.	564.0
Rain tree	32,400.0
Rain tree/Tamarind	101.0
Rambutan	5,244.0
Rambutan/Litchi	793.0
Rambutan/Longan	1,029.0
Recreation area	47.0
Reservoir	2,846.6
Resort, Hotel, Guesthouse	11.2
River, Canal	1,622.2
Road	200.0
Rock out crop	219.0
Roselle	457.0
Scrub	7,244.2
Soil pit	29.8
Soybean	155.0
Sugarcane	12,711.0
Tamarind	169,362.0
Tamarind/Longan	23,443.0
Tamarind/Teak	230.0

Table D.2 The data of land use in Phayao province in 2009 (Continued)

Land use name	Area (ha)
Teak	495,153.0
Teak/Banana	193.0
Teak/Longan	1,040.0
Teak/Mango	137.0
Teak/Longan	1,040.0
Teak/Mango	137.0
Teak/Pterocarpus sp.	1,044.0
Teak/Rain tree	469.0
Teak/Tamarind	920.0
Thai village	13,647.5
Tobacco	3,780.0
Tomato	102.0
Upland rice	43,476.0
Watermelon	427.0

Table D.3 Stock change factor for each type of land use in Phayao province

Land use types	Reference carbon stock	Stock change factor			Carbon stock / ha
		F_{LU}	F_{MG}	F_3	
Mangrove forest	-	-	-	-	-
Evergreen forest	-	-	-	-	238.0[a]
Deciduous forest	-	-	-	-	172.0[a]
Paddy field	-	-	-	-	22.7[b]
Corn	-	-	-	-	17.5[b]
Rubber	-	-	-	-	37.1[b]
Coconut	-	-	-	-	30.3[b]

Table D.3 Stock change factor for each type of land use in Phayao province (Continued)

Land use types	Reference carbon stock	Stock change factor			Carbon stock / ha
		F_{LU}	F_{MG}	F_3	
Longan	-	-	-	-	20.3[c]
Golf course	-	-	-	-	3.6[d]
Grassland	-	-	-	-	66.3[e]

Note: [a], [b], [c], [d], [e] refer to source of information; a: Arunyawat and Shrestha, 2016; b: Patricio, 2014; c: Zemek, 2009; d: Selhorst and Lal, 2011; and MRC, 2017.

APPENDIX E
The Supporting Data

Table E.1 Biomass burned in Phayao province (NASA, 2012)

Province	Agricultural residues (t)	Forest (t)	Total
Phayao	49,711	1,016,113	1,065,824

Table E.2 EF ($t/kg_{dry\ mass}$) of biomass burned (Kanabkaew and Oanh, 2011)

Type of pollution	Rice	Corn	Agricultural residues	Tropical forest
CO_2	11.77×10^{-4}	23.27×10^{-4}	15.15×10^{-4}	15.80×10^{-4}
CH_4	9.59×10^{-6}	4.40×10^{-6}	2.70×10^{-6}	6.80×10^{-6}

Table E.3 Parameter used to calculate biomass burning in the forest (Michel *et al.*, 2005)

Vegetation class	Biomass density (kg/m^2) (B)	Burning efficiency (C)
Evergreen needle leaf	36,700	0.3
Evergreen broadleaf	23,350	0.3
Deciduous needle leaf	18,900	0.3
Deciduous broadleaf	20,000	0.3
Mixed forest	22,250	0.3
Woodland	10,000	0.4
Wooded grassland	3,300	0.4
Closed shrub land	7,200	0.5

Table E.3 Parameter used to calculate biomass burning in the forest (Michel *et al*., 2005) (Continued)

Vegetation class	Biomass density (kg/m^2) (B)	Burning efficiency (C)
Open shrub land	1,600	0.9
Grassland	1,250	1.0
Cropland	5,100	0.6

Table E.4 Parameter used to calculate biomass burning in agriculture (Kanabkaew and Oanh, 2011)

Parameter	Rice	Corn	Soybean	Groundnut and mung bean
The residue to crop ratio (N_1)	1.19	2.00	1.50	1.5
Dry matter to crop residue ratio (D)	0.85	0.40	0.71	0.8
The fraction burned (β)	0.89	0.25	0.76	1.0
The crop specific burn efficiency (F_1)	0.89	0.92	0.68	0.9
The amount of crop production (t) (P)	296.25	421.25	170.00	158.8

Table E.5 The harvested area of rice cultivation (A_2) (DOAE, 2011)

Inside Irrigable area (ha)		Outside Irrigable area (ha)	
Seasonal	Off seasonal	Seasonal	Off seasonal
21,641.60	6,987.68	76,352.16	6,693.8

Table E.6 EF of rice cultivation (IPCC, 2006)

Water manage system in rice cultivation			EF_2 (t ha/day)
Seasonal rice cultivation inside irrigable area	Continuously flooded		21.7
	Release water	Release water 1 time	20.7
		Release water 2 times	15.6
Off seasonal rice cultivation outside irrigable area	Continuously flooded		26.5
	Release water	Release water 1 time	NA

Table E.7 Livestock category and EF from enteric fermentation (IPCC, 2006)

Species/Livestock category	N_2 (head)	EF_3 (t/head)
Dairy cattle	31	2.0×10^{-2}
Native beef cattle, female, age 0-2 years	25,031	3.0×10^{-2}
Native beef cattle, female, age 2 years and over	12,492	0.1
Native beef cattle, male	18,659	0.1
Cattle and hybrid cows, female, age 0-2 years	3,674	4.0×10^{-2}
Cattle and hybrid cows, female, age 2 years and over	3,594	0.1
Cattle and Crossbred Cattle, male	3,056	0.1
Fattening cattle, male and female	190	3.0×10^{-2}
Buffalo native species, female, age 0-2 years	2,898	3.0×10^{-2}
Buffalo native species, female, age 2 years and over	1,418	6.0×10^{-2}
Buffalo native species, male	1,822	6.0×10^{-2}
Swine	15,160	2.0×10^{-3}
Total	88,025	0.6

Table E.8 Livestock category and EF from manure management (IPCC, 2006)

Species/Livestock category	N_3 (head)	EF_4 (t/head)
Dairy cattle	31	9.2 x 10^{-3}
Native beef cattle, female, age 0-2 years	25,031	7.3 x 14^{-4}
Native beef cattle, female, age 2 years and over	12,492	1.5 x 10^{-3}
Native beef cattle, male	18,659	1.7 x 10^{-3}
Cattle and hybrid cows, female, age 0-2 years	3,674	1.8 x 10^{-3}
Cattle and hybrid cows, female, age 2 years and over	3,594	3.88 x 10^{-3}
Cattle and Crossbred Cattle, male	3,056	4.5 x 10^{-3}
Fattening cattle, male and female	190	44.3 x 10^{-2}
Buffalo native species, female, age 0-2 years	2,898	1.4 x 10^{-3}
Buffalo native species, female, age 2 years and over	1,418	2.5 x 10^{-3}
Buffalo native species, male	1,822	2.5 x 10^{-3}
Swine	15,160	6.0 x 10^{-3}
Poultry	260,661	0.2 x 10^{-4}
Total	348,686	0.1

Table E.9 Default value for nitrogen excretion (IPCC, 2006)

Species/Livestock category	Asia
Dairy cattle	0.5
Other cattle	0.3
Buffalo	0.3
Swine	0.5
Poultry	0.8

Table E.10 The number of vehicles (DOH, 2012)

Number of road	MC	PC	LD	HDB	HDT	Total
1	1,920	1,847	3,855	138	1,541	9,301
2	3,748	3,252	6,119	226	1,247	14,592
3	4,914	2,895	7,352	350	2,371	17,882
4	5,649	5,157	6,150	164	1,169	18,289
5	1,137	1,228	3,094	103	971	6,533
6	3,637	2,023	6,955	87	845	13,547
7	294	557	318	25	167	1,361
8	1,554	1,593	3,645	82	511	7,385
9	591	1,769	617	39	300	3,316
10	3,570	1,230	3,887	141	384	9,212
11	2,772	1,056	3,033	3	470	7,334
12	782	681	2,273	69	300	4,105
13	1,548	746	654	34	180	3,162
14	538	382	973	15	301	2,209
15	602	235	915	7	304	2,063
16	584	813	368	6	101	1,872
17	1,831	223	114	0	78	2,246
18	566	58	406	3	78	1,111
19	416	542	160	4	104	1,226
20	2,541	853	2,399	15	114	5,922
21	1,680	186	939	42	142	2,989
22	1,199	1,123	1,759	7	190	4,278
23	1,098	1,210	241	0	67	2,616
24	2,338	1,015	761	0	230	4,344
25	122	3	22	0	3	150
26	2,340	1,064	1,941	2	209	5,556

Note: Motorcycle (MC), Passenger Car (PC), Light Duty (LD), Heavy Duty Bus (HDB), and Heavy Duty Truck (HDT)

Table E.10 The number of vehicles (DOH, 2012) (Continued)

Number of road	MC	PC	LD	HDB	HDT	Total
27	2,444	1,796	3,368	12	241	7,861
28	3,272	661	1,506	0	124	5,563
29	665	743	1,135	9	242	2,794
30	695	116	748	0	132	1,691
31	832	286	681	5	72	1,876
32	368	1,251	196	3	34	1,852
33	1,152	33	517	0	131	1,833

Table E.11 Registration data of vehicles (DLT, 2012)

Type of vehicles	Year	Distance (km/hour)	The number of vehicles	Proportion (Y)
PC	Euro 1 (Pre-2000) 1999-2000	108	391	0.04
	Euro 2 (2001-2004)	108	2237	0.2
	Euro 3 (2005-2011)	108	7462	0.7
MC	Pre-2003	45	42151	0.3
	2004-2008	45	70450	0.5
	2001-2009	45	39613	0.3
LD	2000-2011	104	14,333	1
HDB	2001-2011	90	260	1
HDT	2001-2011	85	2790	1

Table E.12 EF and proportion of vehicles (ESMAP, 2009)

Type of vehicles	Type of fuel	Year of vehicles	EF_5 (t/km)	Proportion (F_2)
PC	Gasoline 91	Euro 1 (Pre-2000) 1999-2000	10.38×10^{-5}	0.4
		Euro 2 (2001-2004)	11.12×10^{-5}	
	Gasohol 95	Euro 1 (Pre-2000)	90.73×10^{-6}	0.1
		Euro 2 (2001-2004)	11.46×10^{-5}	
		Euro 3 (2005-2011)	10.24×10^{-5}	
	Gasohol 91	Euro 2 (2001-2004)	10.00×10^{-5}	0.3
		Euro 3 (2005-2011)	94.38×10^{-6}	
	LPG	Euro 1 (Pre-2000)	88.14×10^{-6}	0.2
		Euro 2 (2001-2004)	10.19×10^{-5}	
		Euro 3 (2005-2011)	11.44×10^{-5}	
MC	Gasoline 91	Pre-2003	48.28×10^{-6}	0.6
		2004-2008	28.57×10^{-6}	
		2009-2011	38.93×10^{-6}	
	Gasohol 91	2009-2011	30.99×10^{-6}	0.4
LD	diesel	2000-2011	20.72×10^{-5}	1.2×10^{-4}
HDB	diesel	2001-2011	47.68×10^{-5}	
HDT	diesel	2001-2011	48.30×10^{-5}	

Table E.13 Industry contributed CO_2 in Phayao (PIO, 2012)

The type of industry	The number of industry
Brick	13

Table E.14 EF of industry (US EPA, 2005)

Type of industry	Type of pollution	EF_6 (t/Mg)	Source
Brick	CO_2	0.3	Brick and structural clay product manufacturing

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List of Publication and Proceeding

Sari, N.S., Prueksakorn, K., Gonzalez, J.C., Arpornthip, T., Areerob, T., Pornsawang, C., Pimonsree, S. (2018). Inventory of Greenhouse Gas Emissions for Phayao Province – An Agricultural City in Thailand. *Chemical Engineering Transactions,* 63, 163-168.

Prueksakorn, K., Keson, J., Wongsai, S., Wongsai, N., Sari, N.S. (2017). Estimation of Carbon Stocks from Land-use Change due to Tourism in Phuket Island, Thailand. *Chemical Engineering Transactions,* 56, 331-335.