THESIS

ANALYSIS OF LAND USE CHANGE AND GREENHOUSE GAS EMISSIONS IN KALASIN PROVINCE, THAILAND

Submitted by

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ABSTRACT

ANALYSIS OF LAND USE CHANGE AND GREENHOUSE GAS EMISSIONS IN KALASIN PROVINCE, THAILAND

Growing global population causes many stresses on the environment, perhaps the most serious is global warming due to Greenhouse Gas (GHG) emissions. Major contributors to GHG emissions include agricultural production and land use change. Southeast Asia is one of the world's fastest growing regions and provides many crops for export, so the land use changes are rapid and not always made in an environmentally conscious manner. The province chosen for this study, Kalasin, is located in a major economic development region with the multi-country East-West Economic Corridor (EWEC) running through it. The EWEC has brought many changes to this province such as expansion of the manufacturing sector, more urban growth to support new factories, and new roads to reach areas which were previously not developed. The largest single land use in Thailand and the Kalasin province is cropland. There have been many changes in farming practices in the province as well, from the types of crops grown to the increasing numbers of commercial farms. These shifts in land use are leading to changes in the amount of GHG emissions and are also leading to land degradation in parts of the province as well. The largest GHGs emissions in agricultural sector come from rice cultivation (45%), followed by biomass carbon stock losses (40%). Some government policies have led to crops being grown on unsuitable lands, which is often associated with greater use of fertilizers and intensive tillage practices applied. Other practices involve draining wetlands, creating rice paddies on unsuitable soils, or clearing forests to farm the area. In this study we look at land use and land use changes throughout the province and use that data to estimate a GHG emissions inventory in the agricultural sector in

order to better understand the effects that growth, land use and land use changes in the Kalasin province have on the environment.

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CHAPTER 1

INTRODUCTION

Growing population and increased demands for food, fiber and energy pose a huge challenge to global food security and environmental sustainability (FAO, 2005). Furthermore, many people continue to suffer from malnutrition; the number of people suffering severe hunger in the world increased from 777 million in 2015 to 815 million in 2016 (FAO, 2017). World Food Programe (2017) reported that there were approximately 815 million people who suffer from starvation and 52 million children have weight too low given their height. Not only does food demand continue to grow every year, but also demand is growing for natural resources such as fuel, clean water, and the land needed for growing food. Thus, to meet global demand for food and other natural resources, agricultural production must grow to meet human population growth. Globally, Bergeron (2010) reported that many forestlands continue to experience deforestation and that land degradation has expanded, while the area of farmland has been growing since the 1980s. Moreover, Gibbs et al. (2010) showed that nearly 13 million hectares of new agricultural land was created in the developing countries between 1980 and 2000. Thus, growing need for agricultural lands continues to be a major driver of land use conversion.

There is much evidence that the Earth is getting warmer which could severely impact society in multiple ways, including human health, natural disasters, food security, and natural resources availability and uses (Mann et al., 1998; Dietz, 1997; McMichael et al., 2006; Haines et al., 2006; Ritchie & Roser, 2018). The major cause of global warming and climate change is anthropogenic greenhouse gas (GHG) emissions, leading to increased carbon dioxide (CO_2) and other GHGs (e.g. N_2O, CH_4) concentration in the atmosphere that could lead to serious climate disruptions (Mercer, 1978). IPCC (2014) reported that seventy-six percent of the net warming due to global GHG emissions is attributable to CO_2, of which is a significant portion is produced from Agricultural, Forestry and Other Land Use (AFOLU) (11%) and fossil fuel and industrial processes (65%). However, it is not only CO_2 that is emitted from the AFOLU sector, but also CH_4 and N_2O. These gases (CH_4 and N_2O) have more warming impact of than CO_2 over a hundred year time scale; a tonne of CH_4 or N_2O has 28 times and 265 times the warming impact of a tonne of CO_2, respectively (IPCC, 2013). Furthermore, forty-six percent of the warming effect of GHG emissions in the AFOLU sector is from N_2O which is generated from soils, followed by CH_4 (45%) which is produced from enteric fermentation, manure management, and rice paddies cultivation (World Resources Institute: WRI, 2005; McMichael et al., 2007; Schwarzer, 2012). Since, AFOLU is a major contributor to global GHG emissions, any activity or disturbance which occurs in this sector, such as deforestation and land use conversion, is likely to affect the global warming.

From the beginning of the industrial revolution until 1992, 30% of the increase in CO_2 in the atmosphere has been from land use conversion (Heil and Selden, 2001). Moreover, the Food and Agriculture Organization of the United Nations: FAO (2014) also reported that GHG emissions from crop and livestock management increased 14% from 2001 to 2011. Population expansion in developing countries leads to further land use conversion to agricultural uses, which contributes to soil carbon losses (Smith, 2008). However, croplands that are converted back to forest or pasture can result in increased soil carbon accumulation (Post and Kwon, 2000; Lal, 2005). Over the decade of 2001-2010, there was a decrease in GHG emissions from land use conversion, and during the same period the rate of deforestation decreased by roughly 10% (FAO, 2017). Therefore, land use change is one of many causes that can influence GHG emissions and soil carbon stock losses which lead to the global warming, while management of forest plantations, decreased deforestation, and afforestation have the ability to store soil and biomass carbon and reduce atmospheric CO_2 concentrations (Terakunpisut et al., 2007).

According to the Gross Domestic Product (GDP) growth data from World Bank (2018), over past the 10 years, Thailand has been one of the most dynamic and fastest growing countries in Southeast Asia. The high GDP growth rate in Thailand not only improves the quality of life of the Thai people, but also contributes to a high rate of land use conversion. As described in above, deforestation, GHG emissions, soil carbon stock losses, and land degradation all result of land use change and subsequent management. Land use changes without a sustainable soil management plan has been a major cause of land degradation in agricultural lands in the country. The northern region of Thailand has soil erosion problems, while the northeastern and the eastern region of the country are faced with soil salinity and low soil fertility. These problems impact not only crop growth and crop yield, but also general environmental quality.

The northeastern region of Thailand is one of two regions where the East-West Economic Corridor (EWEC) passes through. The EWEC is an economic improvement project which connects transportation routes and the trade system between the four countries of Myanmar, Thailand, Lao PDR, and Vietnam (Office of the National Economic and Social Development Board, 2012). The

EWEC stimulates economic activities such as infrastructure development for more efficient product distribution, market expansion, growth in urban areas, increased manufacturing, agricultural production and tourism in the region. This economic corridor is the important route, which connects between south China sea and Indian ocean. This route can improve transportation faster and cheaper. The increased access and economic activities also increase the risk for illegal logging, wood smuggling and increased land use conversion to meet growing land demand. Moreover, since there are increasing building area demands, areas of cropland, grassland, and forestland might be converted to housing, businesses, factories and other urban land uses. Therefore, the EWEC could be a major factor driving land use changes in the region.

In this study, the Kalasin province in northeastern Thailand was selected for conducting a GHG emission inventory and analysis, as this province is part of the EWEC. The Forestland Management Office, Royal Forest Department of Thailand (2015) reported that the forestland in the Kalasin province have decreased from 2006 to 2015 with the expansion of croplands as one of several causes of deforestation. Some forest areas were changed to cash crop production due to the increasing agricultural demand. With its location in the EWEC, Kalasin's recent development plan (2011-2014) had four strategies, including development of agricultural products, development of Wa silk, economic development focused on tourism, and socio-economic development (National Statistical Office Thailand, 2014). This development plan has incentivized increased outputs from the agricultural sector and changes in the farming systems, with a shift from subsistence agricultural production to more commercial farming. The main economic crops of the Kalasin province are rice, cassava, para rubber, and sugarcane. There are also many industrial factories which process agricultural outputs from the province (Kalasin Provincial Agriculture Office, 2016).

The aims of this study were to quantify land use changes and related greenhouse gas emissions from the agricultural sector excluding livestock in the Kalasin province. The GHG inventory builds off of a high resolution, spatially-resolved analysis of land use and management change in the province from 2006 to 2015 (Chapter 2). Emission sources and removal categories include changes in biomass and soil carbon stocks, CH_4 emissions from rice cultivation and from burning crop residues, as well as direct and indirect N_2O emissions from soil management. Analyzing GHG emissions in the region can provide a basis to explore emission reduction strategies for the agricultural sector in the future.

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CHAPTER 2

LAND USE CHANGE IN NORTHEAST, THAILAND

SUMMARY

Increasing global demand for food and natural resources results, in part, from population growth. A major consequence of meeting this increased demand is land conversion, which has important impacts on land degradation and GHG emissions. Thailand has been one of the fastest growing countries in Southeast Asia over the past 50 years. To understand the changing dynamics of this area, land use changes in the Kalasin province, Thailand were studied. The Kalasin province is an important source of agricultural products in Thailand including rice, sugarcane, and cassava. The Kalasin had a development plan from 2011 to 2014, that had the aim of changing the pattern of land use from local farming to commercial farming. Moreover, Kalasin is a province within the East-West Economic Corridor (EWEC). The EWEC connects transportation routes and trade systems between four countries in Southeast Asia. In this study, land use conversion from 2006 to 2015 is analyzed using spatial analysis, land use maps and soil series data of the Kalasin province along the corridor. The results indicate that the most common land use in both years (2006 and 2015) was devoted to cropland, followed by forest, wetlands, settlement, grasslands and other lands, respectively. Croplands and forest decreased from 2006 to 2015, while wetlands, settlement, grasslands and other land uses increased in area during this time period. The area under rice paddy declined between 2006 and 2015, likely due to the unstable rice subsidy program and the decreasing of market price. The major rice land conversion was from paddy field to sugarcane,

most likely because sugar's price and global demand have been rising. This study demonstrates that physical, economic and social factors affect land use change. Moreover, land use conversion related to GHG emission, is often a result of non-suitable land use including deforestation. To evaluate key environmental impacts of land use conversion a GHG emissions inventory should be considered.

INTRODUCTION

Increasing global population leads to increase demands for food and energy uses a considerable challenge to global food security and environmental sustainability (FAO, 2005). In addition, there are many people continue to suffer from malnutrition. Not only is food demand growing every year, but demand is also on the rise for natural resources such as fuel, clean water, and land needed for growing food. Thus, to meet the global demand for food and other natural resources, agricultural growth must increase to account for human population growth. Globally, Bergeron (2010) reported that many forestlands continue to experience deforestation and that land degradation has expanded while the area of farmland has been increasing since the 1980s. Moreover, Gibbs et al. (2010) showed that nearly 13 million hectares of new agricultural land was created in the developing countries between 1980 and 2000.

Many previous studies have quantified impacts of land use change. Meyer and Turner (1992) reported that global land use conversion leads to biodiversity loss, increased hydrological variability, and land degradation. In addition, land use conversion also contributes to global warming, including GHG emissions (Permpool et al., 2016; Leisz et al., 2007; Fearnside, 2000). Changes in soil carbon stocks resulting from land transformation are often substantial, with as much as 50% or more of the topsoil organic matter stocks lost following land conversion from natural forest or grassland to cropland (Da Silva Oliveira et al., 2016; Frazão et al., 2013; Smith, 2008; Del Galdo et al., 2003). Other land use change might lead to non-suitable outcomes; for example, using an area which highly productive cropland for building factories, or building a house in a wetland or a lowland. In the first case, the farmer (and society) would lose fertile soils for growing plants, while in the second case increased risk for flooding and property damage would likely occur. Finally, conversion of marginal lands (e.g., poor soils, steep slopes, unfavorable climate) to crop production would require a high cost of production, due to high fertilizer requirements and intensive land management in order to improve crop yield. Therefore, land use conversion and unsuitable land use change can lead to land degradation problems.

Eswaran et al. (2001) said that the loss of land quality, unfavorable changes in the chemical, physical and biological properties of soils or extreme disturbances to soil are all components of land degradation. They went on to say that human activities including unsuitable land use, lack of proper soil management, and economic growth without consideration of environment consequences can lead to land degradation (Eswaran et al., 2001). These activities lead to decreased soil quality which is detrimental for agricultural production. The Global Assessment of Soil Degradation (GLASOD) reported that from the mid-twentieth century until now, worldwide around two billion hectares of agricultural land, grassland, and forest, worldwide, has been degraded (Gibbs and Salmon, 2015). The largest proportion of global land degradation is in Asia, with roughly 43 percent of the land degraded followed by Africa (20%) and South America (14%) (Gibbs & Salmon, 2015; Cai et al., 2011).

World Bank (2018) reported that the Gross Domestic Product (GDP) growth data over the past 10 years of Thailand is one of the most dynamic and fastest growing countries in Southeast Asia. The high GDP growth rate not only improved the quality of life of the Thai people, but also contributes to a high rate of land conversions. As described in the previous paragraph, deforestation, GHG emissions, soil carbon stock losses, and land degradation all results of land use change. A major cause of land degradation in agricultural lands of Thailand comes from lack of sustainable soil management plan. The northern region of Thailand has soil erosion problems, while the northeastern and the eastern region of the country are faced with soil salinity and low soil fertility conditions. These problems impact not only on crop growth and crop yield, but also general environmental quality.

Agricultural land in Thailand comprises 54 percent of the total land area, while 32 percent is covered by the total land area is forest; and the remaining area is under other land use, (e.g., grasslands and, wetlands). Settlement and urban areas comprise about 12 percent of the country's area (Land Development Department, Thailand, 2017). The historical trend of cultivation and farming area had been largely stable from 1986 to 2006 (Wongsaichue, 2010). The forestland in Thailand has decreased while the agricultural area has grown. The region which has the largest area (17 million hectares or 42 million acres) and population (Approximate 21 million) is northeast Thailand (Department of Provincial Administration, Ministry of Interior of Thailand, 2015). Although the largest proportion of gross national income (GNI) of the northeast region is not agriculture, the northeastern region of Thailand holds potential to generate substantial revenue from agriculture, and is second only to the southern region in this regard. Therefore, the northeast region of Thailand is critical for the Thai agricultural system.

The East-West Economic Corridor (EWEC) passes two regions of Thailand including the north and the northeastern region Thailand. The EWEC is an economic development program which connects transportation routes and facilitates trade between the four countries of Myanmar, Thailand, Lao PDR, and Vietnam (Office of the National Economic and Social Development Board, 2012). The EWEC stimulates economic activities through infrastructure development for more efficient product distribution, market expansion, development of urban areas, increased manufacturing, agricultural productions and tourism in the region. The increased access provided by the EWEC and the new and expanding economic activities also increase the risk for illegal logging, wood smuggling and increased land use conversion to meet growing demand for land. Furthermore, since there are rising urban demands, cropland, grassland, and forestland might be converted to settlement areas or for other purposes. Therefore, the EWEC is a major factor driving land use changes in the region.

Since the northeast region of Thailand, including the EWEC, is important for Thai agricultural production, a major province in the region, the Kalasin province, was selected for this study. Agriculture is the major source of economic activity of the province. According to Land Development Department of Thailand in 2006 and 2015, more than 70 percent of the Kalasin province is in agriculture and agriculture accounts for the majority of the Gross Provincial Product (Office of the National Economic and Social Development Board, Thailand, 2015).

The Kalasin provincial development plan for the four year period from 2011 to 2014 had four main strategies, including the development of 1) agricultural production, 2) Wa silk, 3) tourism, and 4) social quality (National Statistical Office Thailand, 2014). The Kalasin province is an important source of agricultural products such as rice and fresh water fish. Moreover, there is a big reservoir (Lum Pao Dam), which provides water for three districts in Kalasin province including Muang Kalasin, Yang Talat, and Kamalasai. The ready supply of water gives these three districts an agricultural advantage in the province.

The main cash crops of the Kalasin province are rice, cassava, para rubber and sugarcane. Over the past decade, there has been an increasing shift from local (subsistence) farming to commercial farming. Furthermore, the expansion of urban area has also contributed to land use change and to land being used inappropriately, such as using prime agricultural to build houses or factories. This conversion of land to unsuitable uses is one cause of soil problems in the province.

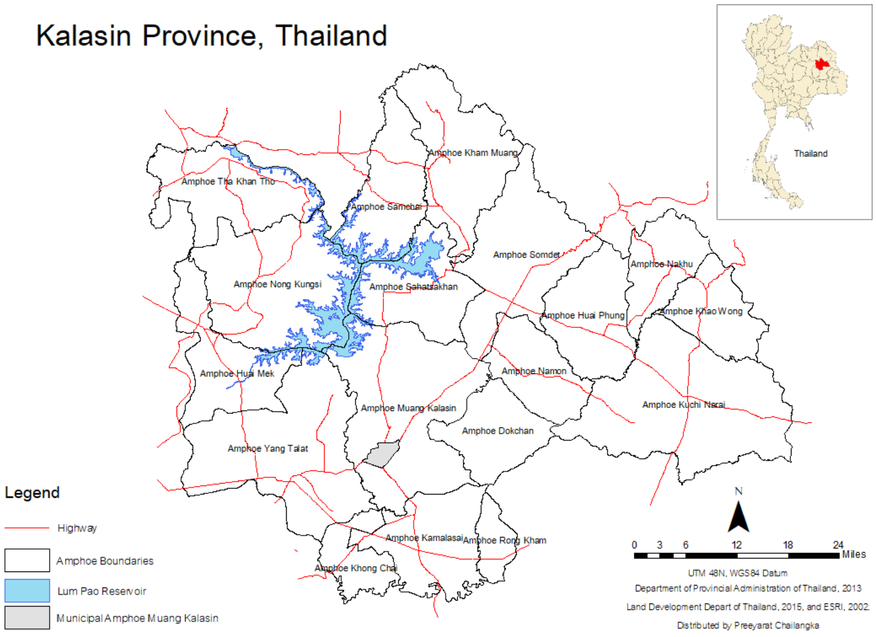
Land use changes in the absence of land use planning and spatially-explicit development plans can lead to detrimental effects for both farmers and the environment. Therefore, studying land use and land use change is necessary for sound land use planning and sustainable natural resource management. The objectives of this study are to understand and quantify the land use and land use change patterns of the Kalasin province over a period of 9 years, from 2006 to 2015 at fine spatial scales, in order to have the required information to assess impacts of land use change on soil degradation and GHG emissions.

MATERIAL AND METHODS

DESCRIPTION OF THE STUDY AREAS

The Kalasin province is located in the center of the Northeastern region of Thailand (16°25'57"N and 103°30'25"E) (Fig. 2.1), about 520 kilometers from the city of Bangkok. It has an area of about 6,947 km^2, comprising 4.5% of the total area of Northeastern Thailand (Office of Commercial Affairs Kalasin, 2009) and is divided into 18 districts.

The Kalasin province falls into three topographical zones; 1) the northern part of the province is dominated by highlands and mountains, making up around 28% of the total area, 2) the central zone makes up 43% and is mostly hills and flatland, 3) the southern zone comprises 29% of the area with topography similar to the central zone, but including the Pao river with a large floodplain. Most of the area in the southern zone is low land that is suitable for agriculture.



UTM 48N, WGS84 Datum
Department of Provincial Administration of Thailand, 2013
Land Development Depart of Thailand, 2015, and ESRI, 2002
Distributed by Preeyarat Chailangka

Figure 2.1: Map of Thailand highlighting the Kalasin Province

Based on the Köppen-Geiger climate classification system, the Kalasin province is an Equatorial tropical savannah with a dry winter (Kottek et al., 2006). The Kalasin province has three seasons including a summer season (from March to mid-May), a rainy season (from mid-May to October), and a winter dry season (from November to February) (Thai Meteorological Department, 2010), with the highest average temperature in April and the lowest December (Fig. 2.2). The average rainfall is 1,407 mm per year.

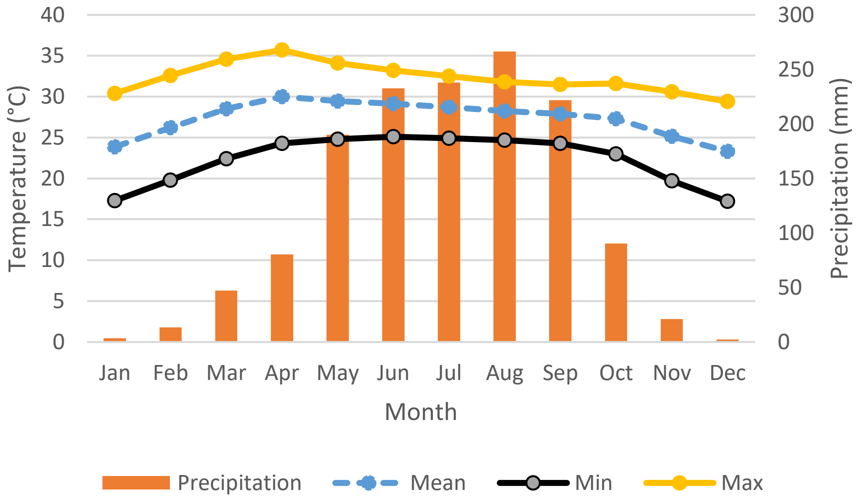


Figure 2.2**:** Monthly rainfall and temperature distribution for 30 years (1981-2010) in the Kalasin, Thailand. Data from Thai Meteorological Department (2010).

There are three dominant soil orders in the kalasin province (Fig. 2.3), including Ultisols, Alfisols, and Inceptisols (Land Development Department, 2015). Seventy percent of the soils in the study area are Ultisols, which are generally acid soils with low capacity to retain base cations from lime and fertilizers (USDA, 1999). Alfisols occupy the second-largest area in Kalasin, making up about 16% of the land area. They are formed primarily under forest or mixed vegetation and are suitable for many crops (USDA, 1999). Most of them are found in the southern zone, and some parts of the highlands in the northern zone of the province. Most Inceptisols are found in the southern zone of the province and making up around 3% of the province. Inceptisols usually occur in river valleys where relatively unweathered sediments are being deposited (USDA, 1999).

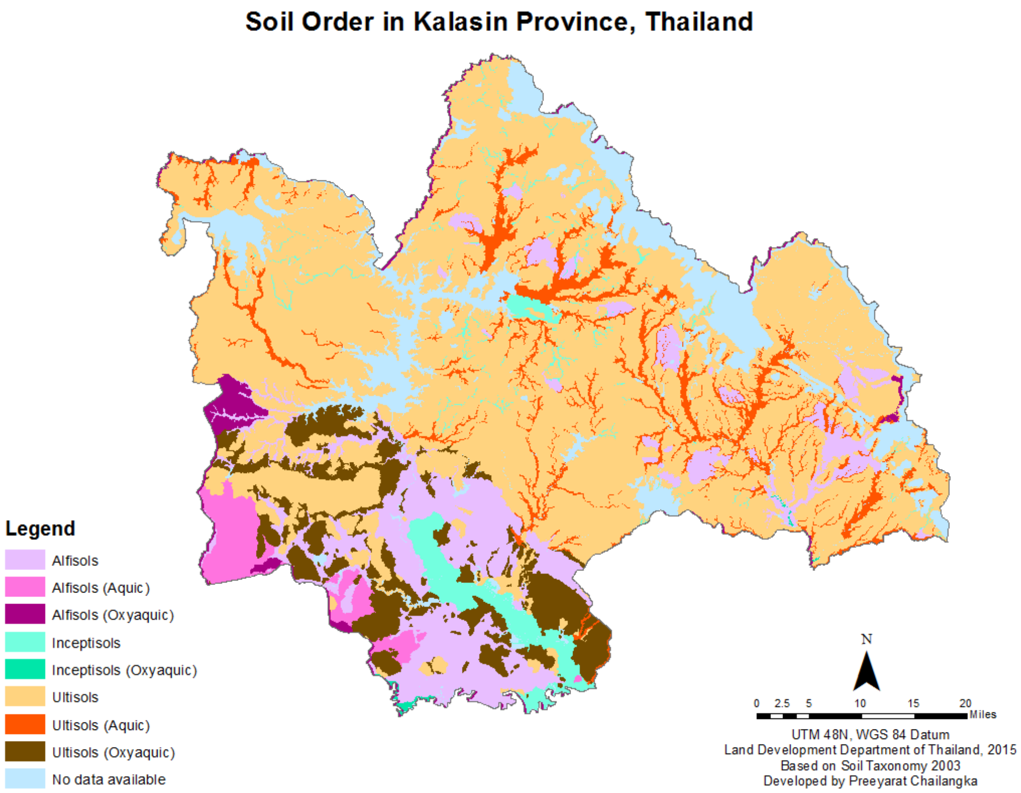
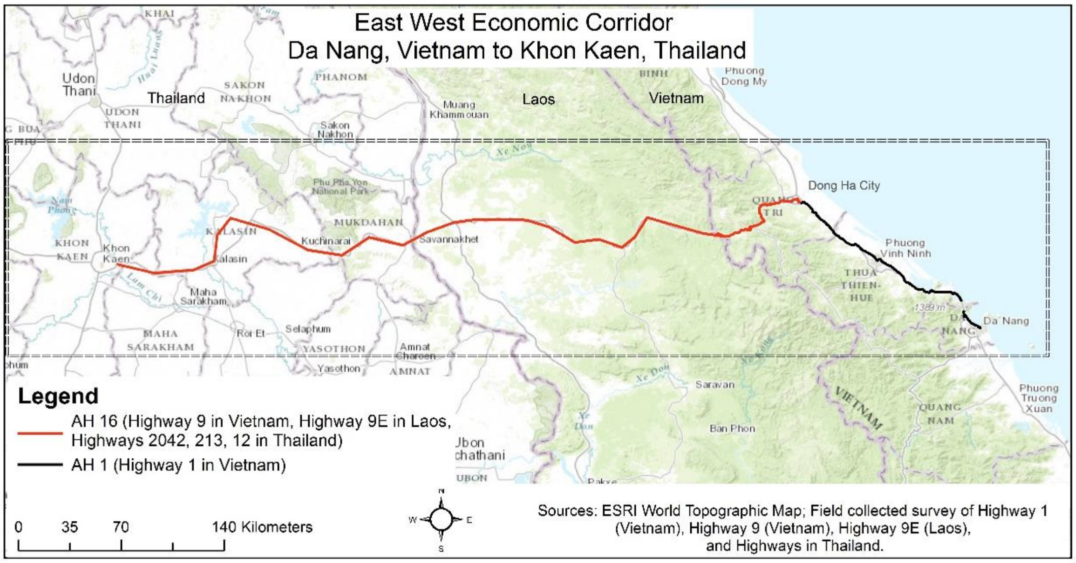


Figure 2.3**:** Soil order map of Kalasin province, Thailand (Land Development Department of Thailand, 2015).

The Kalasin province is in the section of Thailand where the EWEC passes through (Fig. 2.4). The corridor starts from Da Nang, Vietnam, passes through Lao PDR into Mukdahan province, Thailand, Kalasin province, Thailand, and Khon Kaen province, Thailand, respectively. The total distance of the corridor from Da Nang, Vietnam to Khon Kaen, Thailand is around 730 km. The Asian Development Bank (ADB) planned the EWEC project in 1998 (ADB, 2010; Pholsena, 2014; Leisz et al., 2016). However, the roads shown in Figure 2.4 were improved by 2006 and ready for full use first in 2007, which is around the first year of this study (2006-2015). Numerous studies have shown that the impacts of building roads can improve rural areas, support development, and decrease the poverty of the people in rural areas (Leisz et al., 2016). However, creating roads in rural areas, can have both positive effects, including remote area development and increasing economic growth in the rural area, but also has some negative impacts from land conversion including deforestation and soil degradation (Forman and Alexander, 1998; Soares-Filho et al., 2004; Cropper et al., 2001; Mamingi et al., 1996; Leisz et al., 2016).


East West Economic Corridor
Da Nang, Vietnam to Khon Kaen, Thailand

Sources: ESRI World Topographic Map; Field collected survey of Highway 1 (Vietnam), Highway 9 (Vietnam), Highway 9E (Laos), and Highways in Thailand.

Figure 2.4: The East-West Economic Corridor (EWEC) from Da Nang, Vietnam to Khon Kaen province, Thailand (Leisz et al., 2016). The study area, the Kalasin province, Thailand is in the western part of the EWEC.

TOOLS AND DATA SOURCES

ArcMap program version 10.5 was used to carry out spatial analysis to compare land use and land use changes of the Kalasin province, Thailand, between 2006 and 2015. It was used for mapping and editing tasks, as well as for spatial (map) analysis. The land use and land use maps of the province are in the shapefile format and registered to the World Geodetic System (WGS) 1984 UTM zone 48 north. The maps were created by the Land Development Department of Thailand from the Landsat 5 satellite- Thematic Mapper (TM) data, orthophotos, and field surveys (Land Development Department, 2015). Other spatial data used included provincial and district boundary maps and the road center-line maps that were created by the Department of Provincial Administration, Thailand. The soil series map of the Kalasin province which was developed by the Land Development Department of Thailand, was also used in this study for mapping soil properties.

Data on historical trends of forestland area in Thailand and the Kalasin province were produced by the office of the Forestland Management, Thailand, along with the land use data maps (for 2006 and 2015).

Statistical information regarding cash crop cultivation in the Kalasin province, including area under crop cultivation, crop yield, fertilizer input, and crop price, was provided by the office of Agricultural Economics, Thailand.

METHODS

Primary data sources used, information flow and analysis steps used to assess land use and land use changes are shown in Figure 2.5.

The land uses of the Kalasin province, Thailand from 2006, and 2015 were classified into six main categories including forestland, cropland, grassland, wetland, settlement, and other land (Fig. 2.6 and Fig. 2.7), which correspond to the land use categories defined by the IPCC for national greenhouse gas inventory (IPCC, 2006) and the same classification has been adopted by the United Nations Framework Convention on Climate Change (UNFCCC, 2014). Since the cropland category makes up the largest proportion of the province, it was subdivided into another seven groups including rice paddy, sugarcane, cassava, para rubber, eucalyptus, other annual crops, and other perennial crops, in order to examine in more detail the land conversions involving cropland (Fig. 2.8 and Fig. 2.9). Land use maps from two different years (2006 and 2015) were overlaid to see the land use changes between those years, supplemented by longer term data on historical trends for forestland in Thailand and the Kalasin province.

Soil series maps based on the Characterization of Established Soil Series Reclassified According to Soil Taxonomy 2003 (Malairojsiri et al., 2004) were used to classify the soil into eight soil texture types; loamy sand, sandy loam, loam, sandy clay loam, clay loam, clay, silty clay loam, and sand, based on attributes given for each of the map units. Each soil texture type was further classified into two groups of soil fertility in the study area including low and moderate soil fertility, based on the criteria for the soil fertility classification of Land Development Department (1980) (Table 2.1).

Table 2.1: Soil fertility criteria (Land Development Department, 1980).

Soil fertility level	**OM[a] (%)**	**BS[b] (%)**	**CEC[c] (me/100 g clay)**	**P[d] (ppm)**	**K[e] (ppm)**
Low	< 1.5	< 35	< 10	< 10	< 60
Moderate	1.5-3.5	35-75	10-20	10-25	60-90
High	> 3.5	> 75	>20	> 25	> 90

[a] Organic Matter
[b] Base Saturation
[c] Cation Exchange Capacity (me/100 g clay)
[d] Phosphorus in parts per million
[e] Potassium in parts per million

The next step was to overlay the land use maps (2006 and 2015) and the soil texture map and analyze through the union function in ArcMap for the land use/cover maps, and land use changes, and the soil fertility map in order to analyze the relationship between land use changes, soil types, soil fertility and the level of soil organic matter in the Kalasin province.

To understand the dynamics of cash crop conversion in this study area, trends of crop prices for rice, cassava, and sugarcane were analyzed along with the cropland area changes between 2006 and 2015.

To assess impacts on land use change of the EWEC, we assumed that highways 12 and 2116, which pass through this study area, are the main transportation routes through this section of the EWEC. In order to study land use change around this route, road line and the land use change map between 2006 and 2015 were combined using the union function in ArcMap. A 5 km buffer zone from the route was created in order to study the conversion of land use/cover in this area versus the changes outside the buffer zone.

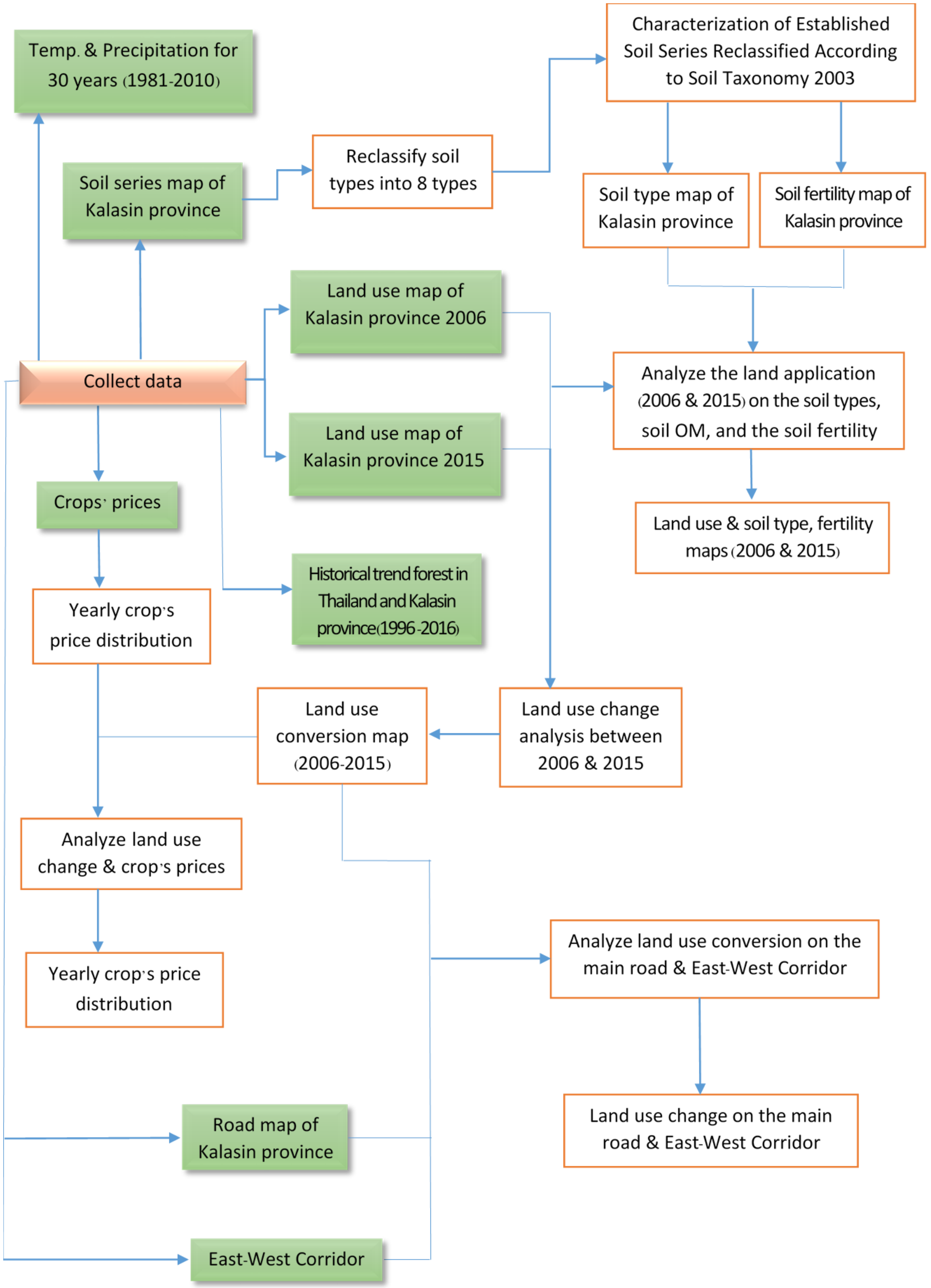


Figure 2.5**:** Flow chart showing the analysis steps and spatial data products from the assessment of land use and land use change in the Kalasin province, Thailand.

RESULTS AND DISCUSSION

LAND USE CONVERSION

Figure 2.6-2.7 show the land use map of the Kalasin province in 2006 and 2015,

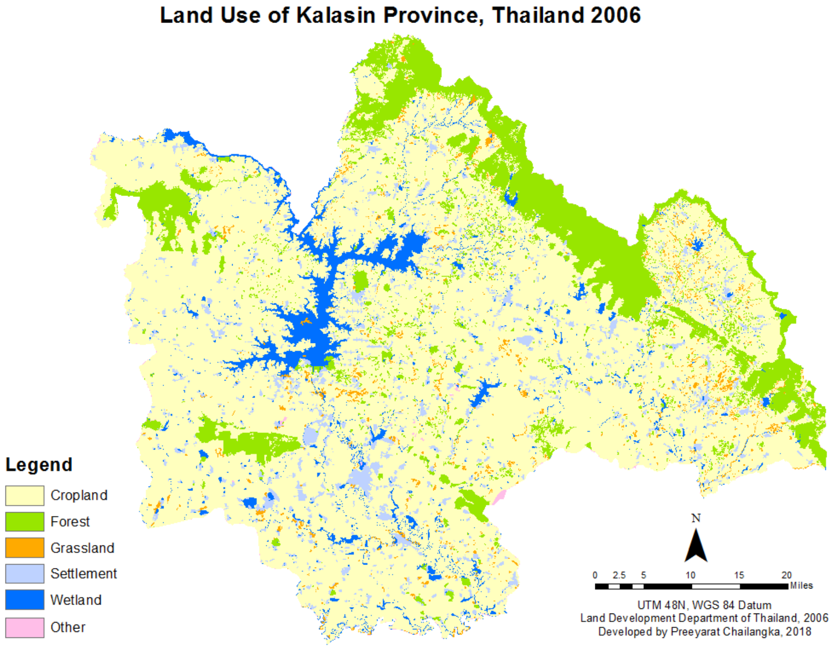


Figure 2.6: The land use map by category of the Kalasin province, Thailand 2006.

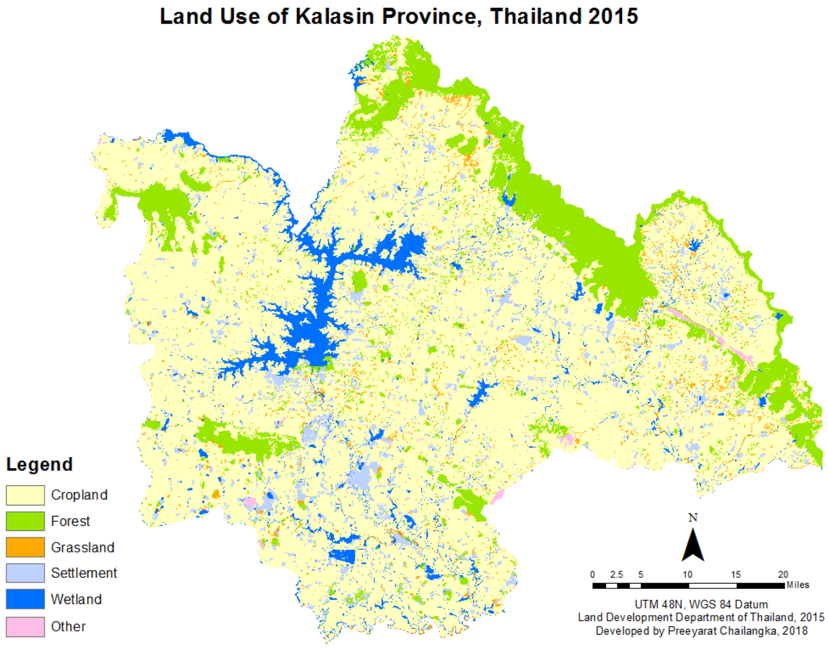


Figure 2.7**:** The land use map by category of the Kalasin province, Thailand 2015.

Figure 2.8 and 2.9 show the cropland sub-categories map of the study area in 2006 and 2015, there are seven cropland sub-categories as well as the area outside the cropland, which includes forestland, grassland, wetland, settlement, and other land.

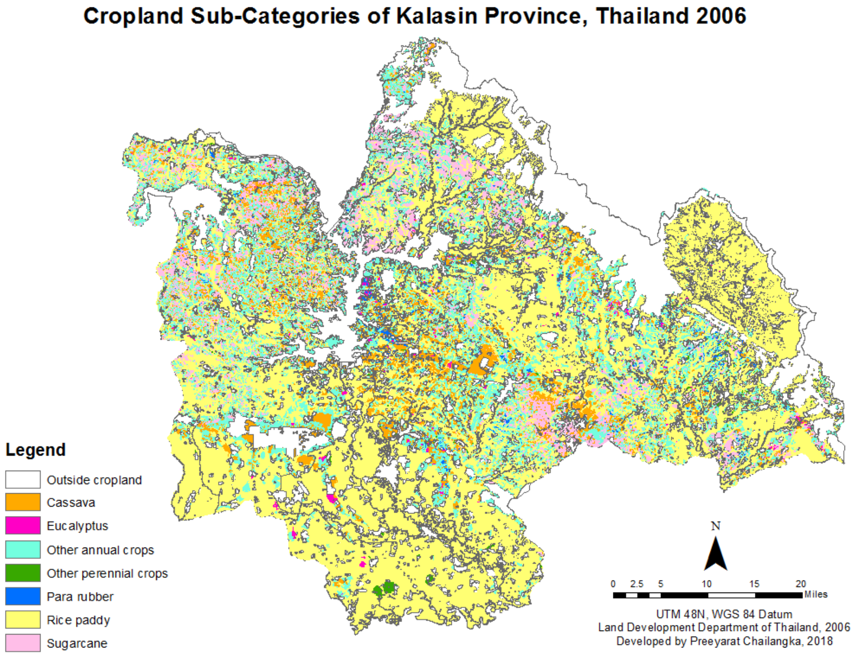


Figure 2.8**:** The cropland map by sub-category of the Kalasin province, Thailand 2006.

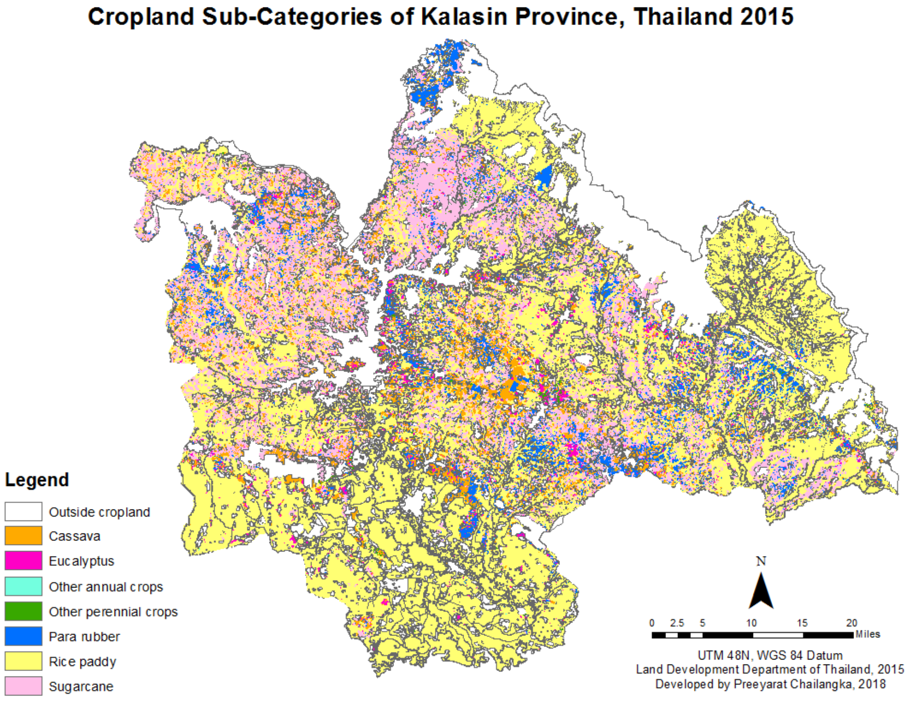


Figure 2.9**:** The cropland map by sub-category of the Kalasin province, Thailand 2015.

Table 2.2 shows land use in 2006 and 2015 by category and sub-category. The largest proportion in both years was cropland, followed by forestland, wetland, settlement, grassland and other land. In both years, the largest area of cropland was in paddy field (59% and 56% of cropland in 2006 and 2015, respectively). However, the area under rice in the Kalasin province in 2015 declined from 2006, which was similar to the trend for rice in the entire country (Fig. 2.10). Overall the rice area in Thailand was quite stable from 2005 to 2009 followed by a sharp increase (of 12%) in 2010 and continued growth in 2011 due to the rice subsidy program of the Thai government at that period (2010-2012). Therefore, the farmers in Thailand had a motivation to grow more rice. However, the total area of rice paddy in Thailand dropped off from 2012 to 2015 because the rice subsidy program was ended in 2013.

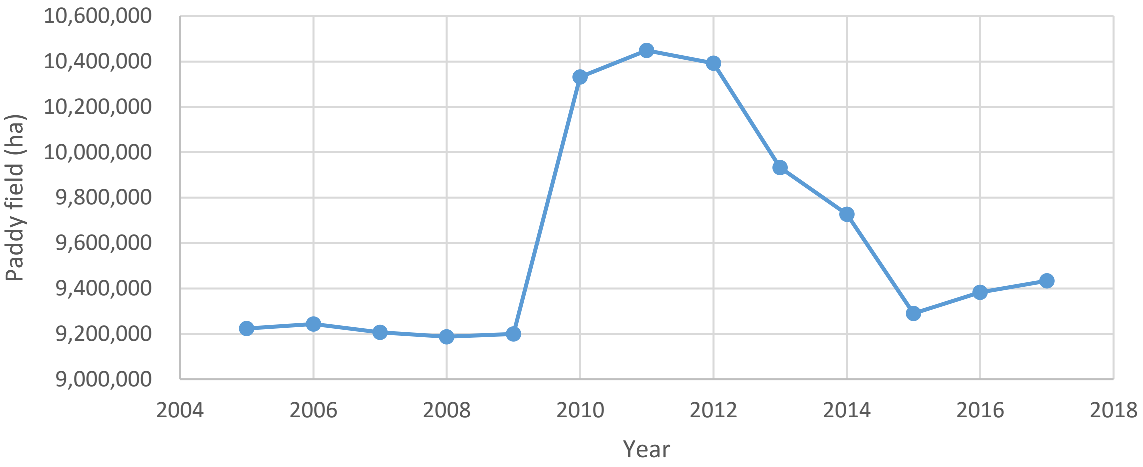


Figure 2.10**:** The total area of paddy fields from 2005 to 2017 in Thailand (Office of Agricultural Economics of Thailand, 2017).

Table 2.2**:** Area of different land uses in the Kalasin province, Thailand in 2006 and 2015. (-) sign indicates that mean area and percent decreased.

Land Use Category	Land Use	2006 (ha)	2015 (ha)	Change (ha)	Change (%)
Forest		97,597	90,572	-7,026	-7
	Dense deciduous forest	73,537	61,086		
	Dense evergreen forest		5,994		
	Dense forest plantation		12,841		
	Disturbed deciduous forest	15,484	10,633	-4,851	-31
	Disturbed forest plantation	8,575	17	-8,558	-100
Cropland		514,699	507,728	-6,971	-1
	Active paddy field	303,705	283,852	-19,853	-7
	Cassava	47,021	52,760	5,739	12
	Eucalyptus	3,038	12,305	9,267	305
	Mango	627	1,760	1,133	181
	Para rubber	3,765	33,439	29,674	788
	Sugarcane	44,897	121,469	76,571	171
	Others	111,646	2,144	-109,502	-98
Grassland		11,947	15,251	3,305	28
	Grass	1,084	1,637	553	51
	Grass plantation	-	7	7	100
	Pasture	-	466	466	100
	Shrubland	10,128	11,880	1,752	17
	Abandoned paddy field	624	376	-247	-40
	Abandoned area	111	54	-57	-51
	Abandoned field crop	-	832	832	100
Settlement		33,359	38,788	5,430	16
	Agricultural product trading center	-	359	359	100
	City, Town, Commercial	4,723	4,839	116	2
	Factory	808	1,416	607	75
	Institutional land	3,147	5,667	2,520	80
	Cattle farm house	6	214	208	3,674
	Resort, Hotel, Guesthouse	-	78	78	100
	Village	22,872	23,071	200	1
	Shrimp farm	1,526	1,491	-35	-2
	Fish farm	194	1,528	1,334	689
	Abandoned aquacultural land	84	12	-72	-86
	Other settlements	-	114	114	100
Wetland		35,692	38,746	3,054	9
	Reservoir	25,693	24,207	-1,486	-6
	River, Canal	3,763	4,059	296	8
	Irrigation canal	238	909	670	281
	Lake, Lagoon	4,583	5,744	1,161	25
	Farm pond	587	1,622	1,035	176
	Marsh and Swamp	829	2,205	1,376	166
others		1,196	3,405	2,209	185
	Cemetery	-	151	151	100
	Garbage dump	77	37	-40	-52
	Golf course	-	292	292	100
	Landfill	-	72	72	100
	Laterite pit	9	228	219	2,552
	Recreation area	32	113	81	254
	Rock out crop	-	1,281	1,281	100
	Soil pit	217	362	146	67
	Other miscellaneous	7	13	6	98

Results indicate that cropland and forestland decreased between 2006 and 2015, while wetlands, settlement, grasslands, and other land areas increased (Table 2.2). Fourteen percent of the Kalasin province was under forest in 2006. This decreased by 7,026 hectares, or 7.2% in 2015 and was largely converted to cropland, grassland, settlements, and other land uses, with most of the area going to cropland (Table 2.3). However, not only forest was converted to other land use, but some cropland and grassland were changed to forestland and thus, the total forest area of the Kalasin province in 2015 did not drop as much as the area of deforestation (Table 2.3). Of the forest converted to cropland (Table 2.4), most went to sugarcane (around 3,439 ha), followed by para rubber (2,205 ha) and cassava (1,795 ha). Although forest, grassland, and wetland areas were converted to cropland in the province, the total cropland area still declined by 6,971 ha due to cropland conversions into grassland, forest, and settlements (Table 2.2 and Table 2.3). Rice and other crops, including mixed field crops were the only two sub-categories that decreased from 2006 to 2015, while sugarcane, cassava, para rubber, eucalyptus, and mango increased during this time period (Table 2.2). Based on the limited data available, the classification of land use in 2006 has less detail than in 2015, thus there is the strong possibility that some polygons in more aggregate classes (in 2006), such as the mixed field crops category, were split into many crops such as sugarcane, cassava, and para rubber in 2015 (Table 2.4). As a result, the implied reduction in area of mixed field crops may not be real.

Table 2.3**:** Land use change from 2006 to 2015 by the six main categories (hectare)

2015 2006	forest	cropland	grassland	settlement	wetland	other
forest	82,702	9,301	1,992	1,182	-	1,023
cropland	5,697	488,180	6,682	4,324	-	641
grassland	1,279	4,347	5,701	366	127	58
settlement	322	1,456	101	29,494	105	13
wetland	45	1,967	678	786	41,007	34
other	-	42	10	2	2	174

Table 2.4: Land use change from 2006 to 2015 by sub-category (hectare)

2015 2006	forest	rice	cassava	eucalyptus	para rubber	sugarcane	other crops	grassland	shrubland	mixed field crop
forest	83,189	1,365	1,795	493	2,205	3,439	46	213	1,737	-
rice	551	272,242	2,240	1,464	2,106	15,759	329	291	1,264	-
cassava	771	613	17,873	1,594	7,191	17,773	193	134	208	-
eucalyptus	435	74	356	1,171	334	362	80	49	13	-
para rubber	359	20	274	392	2,226	202	86	2	8	-
sugarcane	252	784	6,582	1,188	6,428	28,703	258	43	149	-
other crops	484	18	160	154	133	127	142	16	47	-
grassland	143	172	42	26	18	224	0	282	124	-
shrubland	1,131	816	705	474	383	1,151	36	70	4,820	-
mixed field crop	2,874	5,552	22,145	5,127	12,123	52,976	944	881	2,708	-

The historical forest trend in Thailand from 1961 to 2016 (Fig. 2.11) showed that the forest area for the entire country has declined since 1961. It went down from 27,362,850 ha in 1961 to 16,347,969 ha in 2016 (Office of the Forestland Management, Thailand, 2017; Charuppat, 1998; Lakanavichian, 2001). As can be seen in the Figure 2.11, forestland saw an apparent sharp increase in 2000. However, this apparent change may not be real due to inconsistencies in the land use/land cover interpretation based on the satellite images and the field survey information (Lakanavichian, 2006). Furthermore, Wongsaichue (2010) indicated that there was an increasing trend towards planting orchard and perennial trees between 1986 to 2006, while paddy fields and other cropland areas decreased. Therefore, it is possible that some perennial plantations were combined into the forestland during the interpretation of the satellite images. If this is the case, then it would explain the sharp increase noted between the late 1990s and early 2000s in forestland.

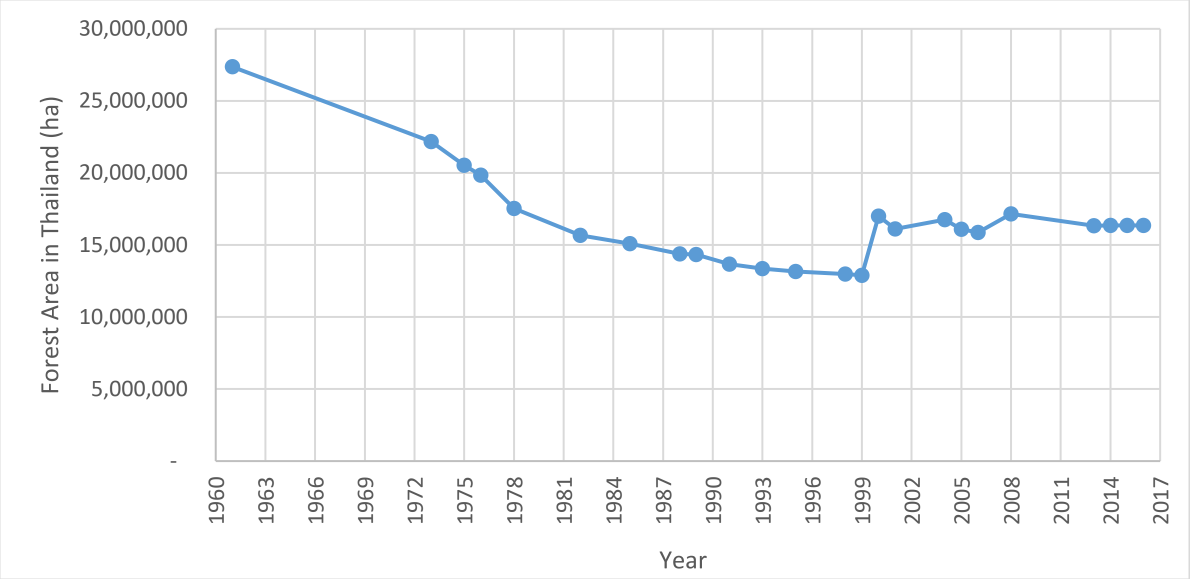


Figure 2.11: The historical forest area trend from 1961 to 2016 in Thailand (Office of the Forestland Management, Thailand, 2017).

Thailand has been one of the top three rice exporting countries (International Trade Centre, 2017) and rice cultivation still makes up the biggest proportion of cropland in the Kalasin province (Table 2.2). However, the area under rice fell by 3% between 2006 and 2015 whereas sugarcane and cassava increased by 15% and 1.3%, respectively. FAO (2018) reported that world prices for rice have decreased since 2012. In contrast, global sugar consumption has been increasing since 2009, due in part to increased use of sugarcane for ethanol production. As a result of the world sugar price increasing (United States Department of Agriculture, 2017) the prices in Thailand have increased since 2009 (Fig. 2.12). Thus, it is very probable that the changes in the price and demand for specific agricultural products has driven much of the observed land use conversion. Over the nine years considered here, paddy field converted to sugarcane amounted to 15,759 ha, with smaller areas converted to cassava and para rubber (Table 2.4). Similar to paddy field conversion, cassava and shrubland were also converted to sugarcane which accounts for the bulk of the land conversion from cassava and shrubland areas (Table 2.4).

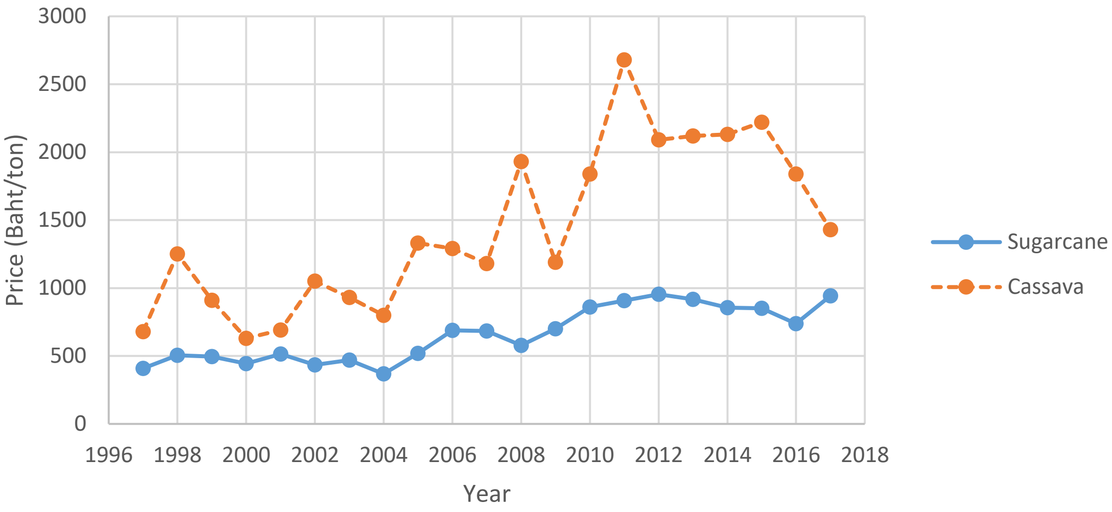


Figure 2.12**:** Average yearly price of sugarcane and cassava in Thailand from 1997 to 2017 (Office of Agricultural Economics of Thailand, 2017).

The area covered by grasslands in the Kalasin province, including hay fields, pasture, shrubland, abandoned paddy fields, abandoned field crop, and other abandoned areas occupied 15,252 ha in 2015, an increase of 3,305 ha since 2006 (Table 2.2). Over that period, about 37% of the grassland in 2006 (4,347 ha) was transformed into cropland, while 48% (5,701 ha) of grassland was unchanged. However, a large area (6,682 ha) of cropland, including mixed field crops and paddy fields, as well as some forest, were changed to grassland, resulting in the net overall increase in the area covered by grasslands.

As described in the previous section, the settlement area of the Kalasin province increased by 5,430 ha over the nine years considered, including increases in urban and commercial areas, factories, institution lands, barns, villages, and fish farms. The Department of Provincial Administration, Ministry of Interior, Thailand (2006-2015) reported that the population in the Kalasin province increased by 9,641 people (from 975,526 people in 2006 to 985,203 people in 2015), which helped to drive an increase in the settlement area. In addition, fish production in the Kalasin province has grown since 2001, which can be observed in the growth of land area classified as fish pond. Moreover, as described in the introduction, the Kalasin province had the strategy to improve production of agricultural products from 2011 to 2014. As a result, factory and agricultural product trading centers increased in support of increased marketing and trading of agricultural products, in line with the government policies. It should be noted that there are more land use details included on the land use map for 2015 than 2006. Categories included in 2015, but missing in 2006 are the sub-categories of pasture, grass plantation, bus station, railway station, harbor, resort, hotel and guesthouse. It is clear that there are more details in the 2015 than 2006 maps, most likely due to the higher resolution of the imagery, the air photos and orthophotos used in 2015 as compared to the data sources for 2006, which was Landsat 5 TM imagery.

The wetland land use of the Kalasin province, including reservoirs, rivers, canals, lakes, irrigation canals, farm ponds, marsh and swamp increased by 3,054 ha. The main increase was in area devoted to farm ponds, lakes, marsh and swamp. The Land Development Department of Thailand (2015) assisted with farm pond creation to help the farmers cope with drought problems. Additionally, The Geo-Informatics and Space Technology Development Agency of Thailand (2011) reported severe flooding in the Kalasin. Thus, there is a possibility that part of the increased area of marsh and swamp in 2015 may have been a consequence of the large floods in 2011.

For all cropland sub-categories conversions are significant and mentioned above. Maps are provided in the appendix section, including forestland, rice paddy, sugarcane, cassava, para rubber, and annual crops conversions

SOIL FERTILITY, SOIL TEXTURE AND LAND USE

Figure 2.13 shows the soil texture map of the Kalasin province, which was developed from the soil series and soil order maps obtained from Land Development Department (2015).

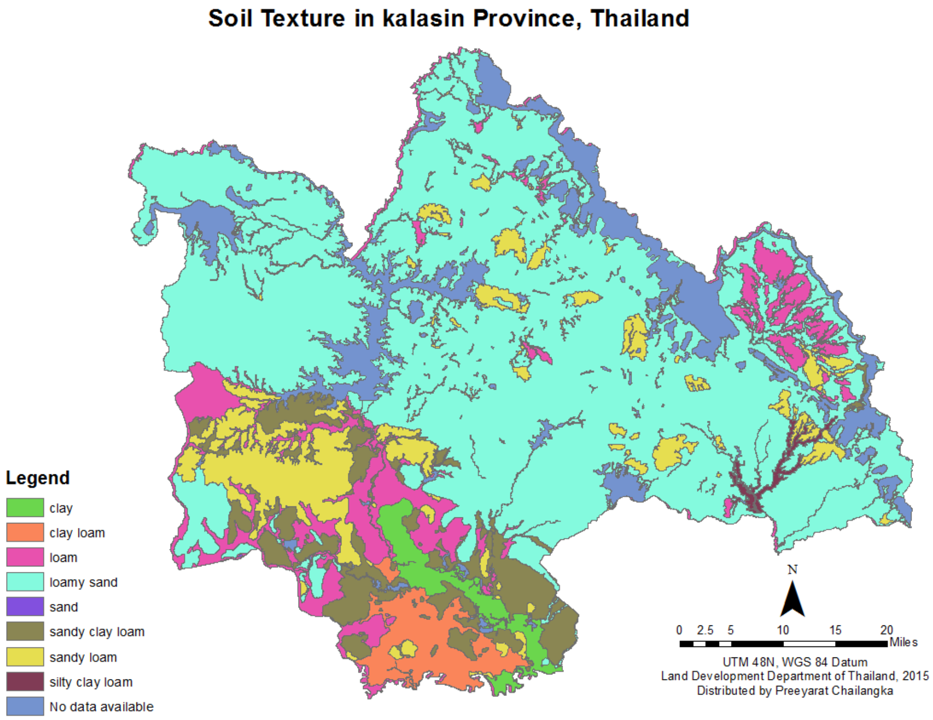


Figure 2.13: Soil texture map of the Kalasin province, Thailand (Land Development Department of Thailand, 2015).

Loamy sand occupies the largest percentage of different texture types (59% of the area) found in the Kalasin province, followed by sandy loam, loam, sandy clay loam, clay loam, clay, silty clay loam, and sand (Fig. 2.4). Around 11% of the land area has no reported soil texture, including rock out crop, cliff, slope complex areas, and water surfaces.

After considering land use in relation to the soil texture map, it was found that 40% of loamy sand texture was under rice paddy area in 2006, followed by 21% of other annual crops, such as mixed field crops, watermelon and corn being grown on loamy sand textured soil in 2006. In 2015 the largest area of land use on loamy sand texture was rice field (37%), followed by sugarcane (25%). Moreover, most of cassava, sugarcane, rice, para rubber, and eucalyptus in the Kalasin province is grown on loamy sand texture.

Soil fertility in the Kalasin province is divided into three categories: low fertility, moderate fertility, and unknown fertility areas of which include rock out crops, cliffs, complex slope areas, and water areas (Fig. 2.14). The largest area of the province, about 80% of the total area, is classified as having low soil fertility. Ten percent of the Kalasin province is classified as having moderate soil fertility and another 10% is unknown. Figure 2.5 shows that most of the soil in the Kalasin province are classified as low fertility. However, 44% of the soil in the study area has moderate organic matter (1.5-3.5% OM), and 45% of the soil has low organic matter (< 1.5% OM).

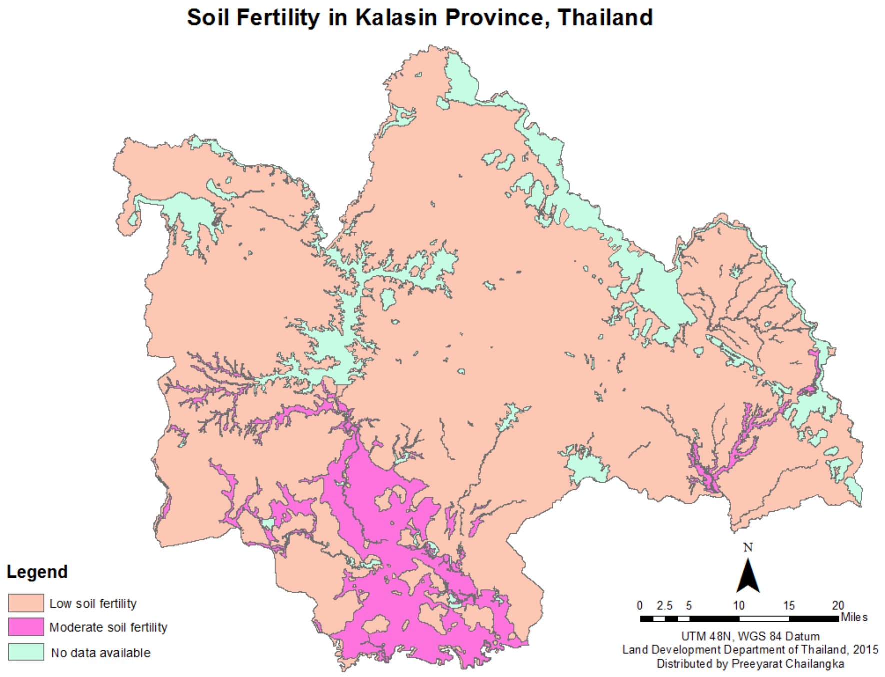


Figure 2.14**:** Soil fertility map of the Kalasin province, Thailand (Land Development Department of Thailand, 2015).

When investigating land use in conjunction with soil fertility in the study area, it was found that the largest amount of low fertility area in the province was used for growing rice (44%), followed by mixed annual crops (20%), forest (9%), cassava (8%), sugarcane (8%), settlement (6%), and other lands; para rubber, other perennial crops, and grassland covered 5% of this area in

2006. The largest area of land use associated with low soil fertility areas in the province in 2015 was rice (41%), which is a decrease in area by 3% from the 2006 data. This land use was followed by sugarcane (22%), cassava (9%), forest (8%), settlement (7%), para rubber (6%), and other lands; eucalyptus, other perennial crops, and grassland (7%). Area planted in sugarcane increased the most on the low soil fertility area from 2006 when 8% of the low soil fertility area was around 8% to 22% in 2015.

Ninety percent of the area under moderate soil fertility was used for rice paddy in 2006. Interestingly, 4% of this land was covered by settlement area, and this increased to 6% when combined with other lands such as forest, mixed annual crops, sugarcane, cassava, para rubber, and eucalyptus. In 2015, the area of rice paddy on moderate soil fertility land decreased 4% from 2006 (86%), while the area of moderate soil fertility land used for settlement increased to 5%.

It is found that there are loam, clay loam, clay, silty clay loam, and sandy clay loam soils in the areas of moderate soil fertility, which is largely in the south of the study area. Generally, the soil texture types that are able to best store nutrients and water are the heavier textured loam, clay loam, clay, silty clay loam, and sandy clay loam. It is clear that the south zone of the Kalasin province is the most suitable area to grow many crops such as rice, sugarcane, and para rubber because it is covered by good soil quality. However, in the low soil fertility areas, there are areas of loamy sand, sandy loam, sandy clay loam, loam and sand texture soils, most of which are found in the northern, eastern, western, and central areas of the province.

Most of soils in the area in the north zone of the Kalasin province lack nutrients because the soil parent materials in the area are derived from sedimentary rocks which have a low concentration of plant essential elements. Hence, soils are predominately sandy texture, with low fertility, low organic matter content and poor water retention capacity. As shown in Figures 2.13

and 2.14, the southern part of the province has higher soil fertility than other parts due to the finer textured soils. Moreover, the forest and flood plain areas also have moderate soil fertility because of finer textured (clay) soils in the area. Saline soils are also a problem in this province, due in part to unfavorable soil parent material as well as unsuitable management practices. Arunin and Pongwichian (2015) report that there are inland salt-affected soils in the northeastern region of Thailand make up almost 2 million ha and 75% of the salt-affected soils in the region are used for rice paddy. Some soil series in the study area are shallow such that root growth is negatively impacted and some soils contain high amount of coarse fragments, with gravel and rock fragments making up 35% or more of the soil volume.

THE EAST-WEST ECONOMIC CORRIDOR AND LAND USE CONVERSION

The buffer zone of the EWEC described in the methods section comprises around 26% (178,234 ha) of the land area of the Kalasin province. About 8% (14,004 ha) of the total area in the buffer zone was converted from one land use to another between 2006 and 2015 (Fig. 1.25). The largest land use conversion was from cropland to settlement, making up around 2,295 ha. Interestingly, the percentage of total area converted from cropland converted to settlement in the buffer zone (1.3%) was higher than the percentage of the area converted from cropland to settlement over entire province (0.9%), suggesting that the EWEC stimulated more urban area demand around the economic routes than in other parts of the province.

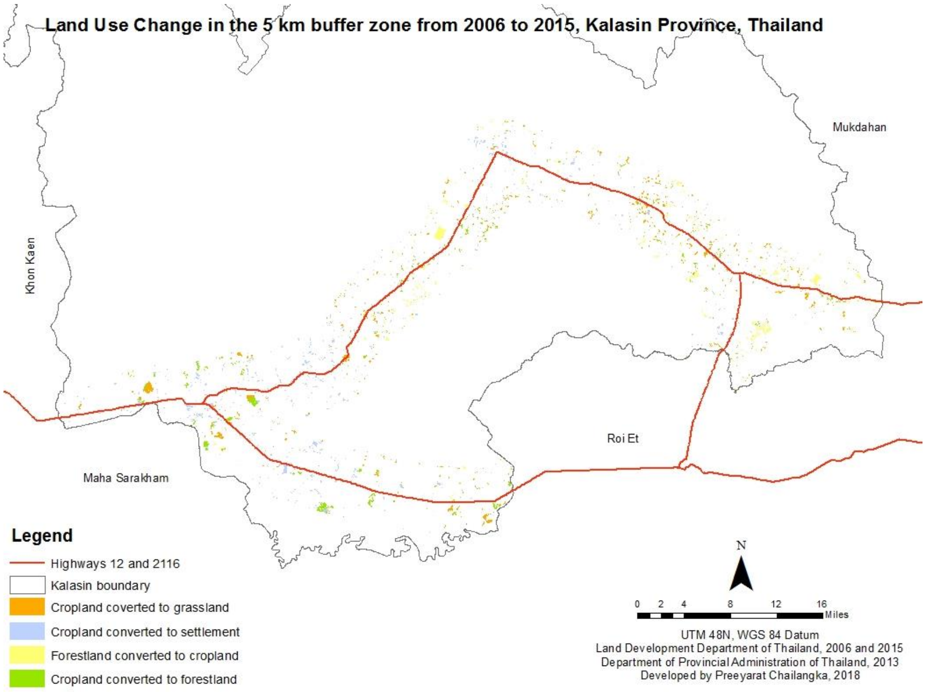


Fig 2.15**:** Land use change map in the 5 km buffer zone of the Kalasin province, Thailand between 2006 to 2015 (Land Development Department of Thailand, 2015; Department of Provincial Adminictration of Thailand, 2013).

The second-largest land use change area in the buffer zone was the change from cropland to grassland, comprising around 1.2% of the buffer zone area. This also is larger than the change from, cropland to grassland in the entire province (1%). Since the roads and economic activities were developed, there are more commercial opportunities and more markets along the corridor. It is possible that the grassland, which increased from 2006 might be land prepared for urban area to support population growth and settlement area demand that is expected to increase in the future. According to Sithilert (2015), the economic stimulation associated with the EWEC has led to increase income distribution and poverty reduction. Sithilert (2015) also notes that the corridor not only increased investment between countries, but also infrastructure development along the routes. If this is the case, then the EWEC is likely a main factor driving the land use changes observed between 2006 and 2015 in the Kalasin province.

Other land use changes are in-line with changes found province wide. Over 2,600 ha of rice paddy was converted to sugarcane in the buffer zone, which was the largest of the land conversions between cropland types. Additionally, 1,520 ha of rice fields were converted to settlement. Although the rice land conversion in the EWEC buffer zone was only 0.9% of all the buffer area, it contains a significant transformation from rice paddy to settlement which was the largest area of land uses converted to settlement in the EWEC.

Similar to the area of rice converted to sugarcane, cassava area converted to sugarcane made up 2,222 ha, which was also a large area. Forestland in the buffer zone was converted to other land uses. A total of 2,011 ha of forestland was converted to sugarcane, para rubber, settlement, and grassland.

As described above, the transformation in the EWEC from 2006 to 2015 had generally similar land use changes as the overall the Kalasin province. Areas of cropland saw the most land use changes and these changes were largely to sugarcane areas. Therefore, it is not only the road building and improvement which connect between rural area and market could impact to land use of the people in the economic route area, but also the farmers and cultivation trends in the province as a whole.

CONCLUSION

The largest land use changes in the Kalasin province from 2006 to 2015 was the forestland converted to cropland, including to sugarcane, para rubber, cassava, rice field, eucalyptus, and other crops. However, based on the limited data available, the classification of land use in 2006 has less detail than in 2015, thus there is the strong possibility that some polygons in more aggregate classes (in 2006), such as the mixed field crops category, were split into many crops such as sugarcane, cassava, and para rubber in 2015 (Table 2.4). As a result, the implied reduction in area of mixed field crops may not be real. According to Lakanavichian (2006), The historical forest trend in Thailand had a sharp increase in 2000 (Fig. 2.11), which might be unrealistic. Therefore, it is possible that the land use/land cover interpretation based on the satellite images and the field survey information might be inconsistent. Furthermore, Wongsaichue (2010) indicated that there was an increasing trend towards planting orchard and perennial trees between 1986 to 2006, while paddy fields and other cropland areas decreased. Therefore, it is possible that some perennial plantations were combined into the forestland during the interpretation of the satellite images. If this is the case, then it would explain the sharp increase noted between the late 1990s and early 2000s in forestland.

It should be noted that there are more land use details included on the land use map for 2015 than 2006. Categories included in 2015, but missing in 2006 are the sub-categories of pasture, grass plantation, bus station, railway station, harbor, resort, hotel and guesthouse. It is clear that there are more details in the 2015 than 2006 maps, most likely due to the higher resolution of the imagery, the air photos and orthophotos used in 2015 as compared to the data sources for 2006, which was Landsat 5 TM imagery.

In both years the largest sub-category of cropland was paddy field, followed by sugarcane. More than 33,000 ha of cassava and rice fields were planted in sugarcane, tracking increases in the world price of sugarcane, the domestic sugar price, and overall increasing demand. The trend of increased area under sugarcane also coincides with the construction of five new sugar factories in northeastern Thailand (Office of the Cane and Sugar board, Thailand, 2016) in order to support increased consumption in the future.

In general, there are several factors that affect land use conversion including physical factors and economic and social factors.

PHYSICAL FACTORS

In high land areas, there was considerable land use conversion from field crops to para rubber while in the lowland areas of the south zone, there was not much land use change. Since the Kalasin province has a huge reservoir in the north called the Lum Pao Dam, there are many plantation areas in the high land near the reservoir. Although the paddy field area declined between 2006 and 2015, there was an increase in aquaculture production including giant freshwater prawn production and many species of freshwater fish due to the plentiful water resources in the province. In addition, the location of factory and product trading centers is also an important factor for land use decision making. Transport routes connecting cultivation areas and markets have a significant impact on land conversion. Moreover, soil conditions for different land uses can aid in interpreting patterns of land use change and can aid in future sustainable land use planning by matching soil types with suitable land uses to get the most sustainable and most economical outcomes.

ECONOMIC AND SOCIAL FACTORS

The population of the Kalasin province has increased and the urban area has been expanded while the demand for agricultural land has also risen. Hence, predominately forest area and some miscellaneous areas provided the land for agriculture and settlement expansion. These activities can lead to deforestation and unsuitable land use, leading to land degradation, soil organic matter depletion, and poor soil quality.

Government policies can lead directly to land use change. For example, the development and implementation of agricultural production policies, reservoir projects, and support of local business development are among the main factors influencing farmers' decisions to grow cash crops.

Global and domestic markets are also factors that can influence land use change. For instance, sugarcane area increased during the same time period that Thailand increased sugar exports, beginning in 2008 (Office of Thai Agricultural Economics, 2010). Since there was more demand for sugar, the area planted in sugarcane increased. Furthermore, the success of some farmers, to change farming patterns. This leads to land use changes and may lead to deforestation due to the demand for more agricultural lands.

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CHAPTER 3

GREENHOUSE GAS EMISSIONS ASSOCIATED WITH LAND USE AND LAND USE CHANGE, NORTHEAST THAILAND

SUMMARY

Global warming affects human health, frequency and intensity of extreme weather, food security, and a range of natural resources. Greenhouse gas (GHG) emissions are the main cause of anthrogenic global warming. The agriculture, forestry and other land use (AFOLU) sector is the second-largest contributor to global GHG emissions. Many studies have found that land conversion such as deforestation and afforestation influences soil carbon sources and sinks. Southeast Asia is the region with the fastest growth in CO_2 emissions over the last 20 years, a major portion of which came from deforestation and land use. To best target a reduction in GHG emissions, a GHG emissions inventory is needed. An inventory helps in understanding the causes of the emissions and provides insight into the optimal way to reduce GHG emissions in the AFOLU sector. In this study, the Kalasin province in NE Thailand was selected for an assessment of greenhouse gas emissions because most of the Kalasin province is covered by agriculture and new economic development in the region contributes to land use conversions. GHG emission estimations were estimated using IPCC Tier 1 methods. We estimated a net emission from the AFOLU sector of 2,682 Gg CO_2 eq. yr^{-1} with the major source from rice cultivation (45%), followed by biomass carbon stock losses (40%). Results indicated that forest conversion to cropland has the largest impact on soil carbon stocks while the forest changed to settlement was

the most important cause for biomass carbon stock decreases. Pre-season flooded rice cultivation produced higher CH_4 emissions than the non-flooded pre-season system. Nitrogen fertilizer inputs in upland (non-flooded) cropping systems accounted for most N_2O emissions. Therefore, studying the optimal way to reduce the emissions from the flooded rice water system in the future needs to be considered a long with N_2O emission reductions.

INTRODUCTION

There is much evidence that the Earth is getting warmer which could severely impact society in multiple ways, including human health, natural disasters, food security, and natural resources availability and use (Mann et al., 1998; Dietz, 1997; McMichael et al., 2006; Haines at al., 2006; Ritchie & Roser, 2018). The major cause of global warming and climate change are anthropogenic greenhouse gas (GHG) emissions, leading to increased carbon dioxide (CO_2) and other GHG (e.g. N_2O, CH_4) concentrations in the atmosphere that could lead to serious climate disruptions (Mercer, 1978). IPCC (2014) reported that 76% of global GHG emissions are comprised of CO_2, of which a large part is produced from Agricultural, Forestry and Other Land Use (AFOLU) (11%) and fossil fuel and industrial processes (65%). However, it is not only CO_2 that is emitted from AFOLU sector, but also CH_4 and N_2O, which have more warming impact of CO_2 over a hundred year time scale; a tonne of CH_4 has 28 and N_2O 265 times the warming impact of a tonne of $CO_{2,}$ respectively (IPCC, 2014). Furthermore, 46% of the warming impact from AFOLU is due to N_2O which is generated from soils, followed by CH_4 (45%) which is produced from enteric fermentation, manure management, and rice paddy (World Resources Institute: WRI, 2005; McMichael et al., 2007; IPCC, 2006; Schwarzer, 2012). Since, AFOLU is an important contributor to global GHG emissions, any activity or disturbance that occurs in this sector such as deforestation and land use conversion affects the overall global warming situation.

From the beginning of industrial revolution until 1992, 30% of the increase in CO_2 in the atmosphere was from land use conversion (Heil and Selden, 2001). Moreover, the Food and Agriculture Organization of the United Nations: FAO (2014) also reported that greenhouse gas emissions from crop and livestock management increased 14% from 2001 to 2011. Population expansion in developing countries leads to further land use, conversion to agriculture, which contributes to soil carbon losses (Smith, 2008). However, croplands that are converted back to forest or pasture and forest can result in soil carbon accumulation (Post and Kwon, 2000; Lal, 2005). Over the decade of 2001-2010, GHG emissions from AFOLU decreased by around 10% mainly because of reductions in deforestation in many countries (FAO, 2014). Therefore, land use change is one of many factors that can influence GHG emissions and soil carbon losses that lead to the global warming, while management of forest plantations, decreased deforestation, and afforestation have the ability to sequester carbon and reduce atmospheric CO_2 content (Terakunpisut et al., 2007).

FAO (2014) reported that Asia is the continent with the greatest shared (44%) of GHG emissions from the agricultural sector. Parts of Asia, especially southern and southeast Asia, have large agricultural areas and most are developing countries with high rates of land use conversion to agriculture. Moreover, Southeast Asia is the region with the fastest growth in CO_2 emissions growth from 1990 to 2010, a major portion of which came from deforestation and land use change (Asian Development Bank, 2016).

Thailand had the second-largest greenhouse gas emissions in Southeast Asia in 2000 (WRI, 2005), of which 70% was from fossil energy, followed by the agriculture and livestock sector (23%) (Office of Natural Resources and Environmental Policy and Planning: ONEP, 2012). Moreover, ONEP (2012) reported that gross greenhouse gas emissions in Thailand in 2012 were 350 Mt CO_2 eq. together with 123 Mt CO_2 eq. removals in the AFOLU Sector, yielding total net greenhouse gas emissions in Thailand of 227 Mt CO_2 eq. According to ONEP (2012), the AFOLU sector can decrease carbon sources and increase carbon sinks with biomass accumulation in forestland and improved cropping system management.

The largest single land use by area in Thailand is agriculture (54%), followed by forestlands (32%) (Land Development Department, Thailand, 2017). According to the Office of Agricultural Economics (2017), 47% of the agricultural area in 2015 was used for rice fields, followed by fruit trees and perennial tree crops (23%), and other annual crops (21%). A variety of land management practices, including increasing of fertilizer application and land practices such as full tillage, burning of crop residues, and pesticide application contribute to GHG emissions in the agricultural sector along with different types of land use change.

A major source of CH_4 emissions is wetland rice. The northeast region of Thailand is the major rice producing area, with over 61% of the rice area in the country (Office of Agricultural Economics, 2017). In addition to paddy rice, northeast Thailand has a diversity of different agricultural and other land use systems and it contains the largest concentration of agricultural land in the country. Moreover, it is a rapidly changing area with diverse factors impacting GHG emissions, including rapid population and economic growth, strong development policies, a growing export economy, and increased communication and trading with neighboring countries and rural improvement.

In this study, the Kalasin province in northeastern Thailand; was selected for GHG emission inventory and analysis. The Forestland Management Office, Royal Forest Department of Thailand (2016) reported that the forestland in the Kalasin province have decreased from 2006 to 2015 with the expansion of croplands as one of several causes of deforestation. Some forest areas were changed to economic crop areas due to the increasing of agricultural demand. In addition, the Kalsin province is in the East-West Economic Corridor (EWEC) which is an economic improvement project that connects transportation routes and trade systems between four countries including Myanmar, Thailand, Lao PDR, and Vietnam (Office of the National Economic and Social Development Board, 2012). Furthermore, the Kalasin's development plan for four years (2011-2014) has four strategies, including development of agricultural products, development of Wa silk, economic development tourism, and development of social quality (National Statistical Office Thailand, 2014). This development plan has incentivized increased outputs from the agricultural sector and changes in the farming systems, with a shift from more subsistence to more commercial farming. The main economic crops of the Kalasin province are rice, cassava, para rubber, and sugarcane. They also have many local industrial factories which support local outputs from the province (Kalasin Provincial Agriculture Office, 2016).

The aims of this study were to quantify GHG emissions from the agricultural sector excluding the livestock sector in the Kalasin province. The GHG inventory builds off of a high resolution, spatially-resolved analysis of land use and management change in the province from 2006 to 2015 (Chapter 2). Emission sources and removal categories include changes in biomass and soil carbon stocks, CH_4 emissions from rice cultivation and from burning crop residues, as well as direct and indirect N_2O emissions from soils. The 2006 IPCC Guidelines for National GHG Inventories for Tier 1 methodologies, as implement in the ALU software package (Natural

Resource Ecology Laboratory, Colorado State University, 2018), were used for inventory calculations. Analyzing GHG emissions in the region can provide a basis to explore emission reduction strategies for the agricultural sector in the future.

MATERIAL AND METHODS

TOOLS

We used the Agriculture and Land Use National Greenhouse Gas Inventory Software (ALU Tool) version 6.0.1 to evaluate greenhouse gas emissions (Natural Resource Ecology Laboratory, Colorado State University, 2018), which is based on the methodologies in the 2006 IPCC guidelines (IPCC 2006). For quantifying land use and land use change we used ArcMap program version 10.5 and LANDSAT 5 satellite-Thematic Mapper (TM) data for the Kalasin province, Thailand between 2006 and 2015.

DESCRIPTION OF THE STUDY AREAS AND VARIABLES INFLUENCING EMISSIONS

Kalasin province, Thailand

The Kalasin province is located in the center of the northeastern region of Thailand (16°25'57"N and 103°30'25"E) (Fig. 3.1), about 520 kilometers from the city of Bangkok. It has an area of about 6,947 km^2, comprising 4.5% of the total area of northeastern Thailand (Office of Commercial Affairs Kalasin, 2009) and is divided into 18 districts.

The Kalasin province falls into three topographical zones: 1) the northern part of the province is highlands and mountains, making up around 28% of the total area of the Kalasin, 2) the central zone (43%) is made up of hills and flatland, and 3) the southern zone makes up 29% of the province, with a topography similar to the central zone, but including the Pao river and its large floodplain area. Most of the area in the south zone is low land that is suitable for agriculture.

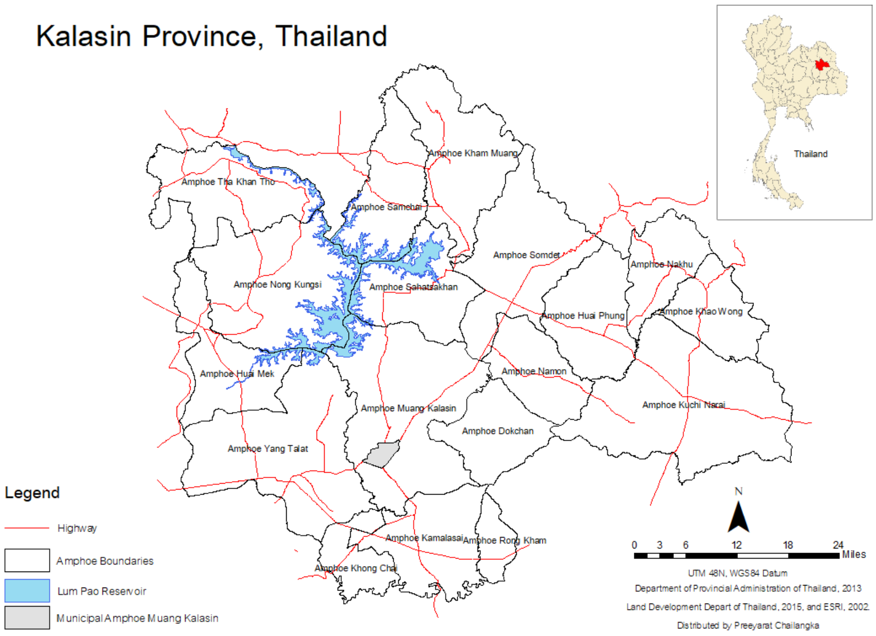

Figure 3.1: Map of Thailand highlighting the Kalasin Province

Temperature and precipitation

Based on Köppen-Geiger climate classification system, the Kalasin province is Equatorial tropical savannah with a dry winter (Kottek et al., 2006). The Kalasin province has three seasons including a summer season (from March to mid-May), a rainy season (from mid-May to October), and a winter dry season (from November to February) (Thai Meteorological Department, 2010), with the highest average temperature in April and the lowest December (Fig. 3.2). The average rainfall was 1,407 millimeters per year.

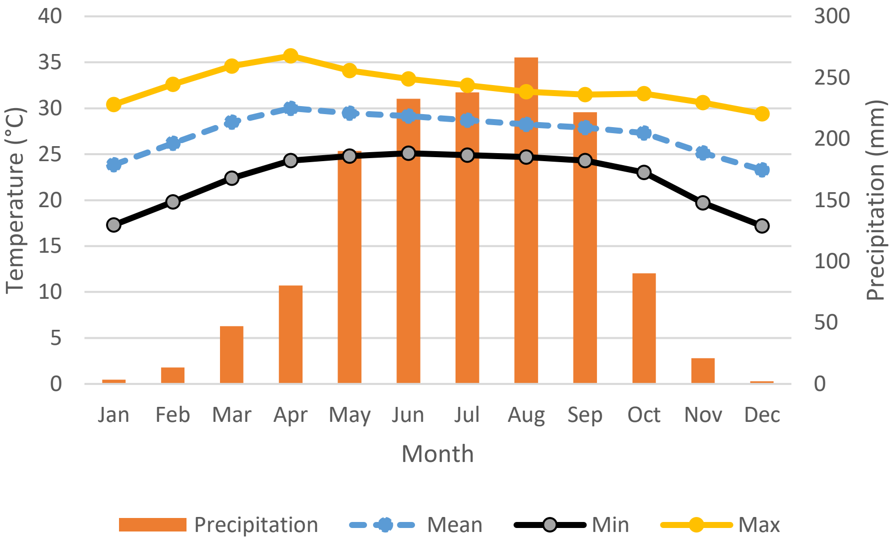

Figure 3.2**:** Monthly rainfall and temperature distribution for 30 years (1981-2010) in the Kalasin, Thailand. Data from Thai Meteorological Department (2010).

Climate and ecological zone

The elevation is 150-500 meters (Land Development Department, Thailand, 2006). Based on the IPCC Guidelines for National Greenhouse Gas Inventories (2006), the Kalasin province is in the Tropical Moist (TRM) climate zone which has mean annual temperature higher than 18 Celsius, the elevation lower than 1,000 meters, and the mean precipitation higher than 1,000 millimeters but less than 2,000 millimeters.

Based on observed climate and vegetation patterns by Food and Agriculture Organization: FAO (2001), the Kalasin province is in two ecological zones, Tropical Moist Deciduous (TAWa) and Tropical Dry Forest (TAWb) zones. Most of the area or 90% of total the Kalasin province area is in Tropical Moist Deciduous (TAWa) zone.

Soil type

A soil series map of the Kalasin province the Land Development Department (Land Development Department, Thailand, 2015) was used to classify soils into three groups, corresponding to the major soil groups defined in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The three soil groups were high activity clay soils (HAC), low activity clay soils (LAC), and wetland soils (WET).

Land use category and sub-category

At the highest level land use was grouped into six classes forest, cropland, grassland, settlement, wetland and other. These correspond to the land use/land use categories defined by the IPCC for national greenhouse gas inventory (IPCC, 2006) and the same classification has been adopted by the United Nations Convention to Combat Desertification (UNFCCC, 2016).

Forestland in the study area was classified into five subcategories including dense deciduous forest, dense evergreen forest, dense forest plantation, disturbed deciduous forest, and disturbed forest plantation and further subdivided by age class. The main characteristics defining the forest categories are the dominant tree species, leaf phenology and senescence, tree height, tree age, and percent tree canopy (Land Development Department, Thailand 2012).

Cropland in the Kalasin province is very diverse, however, we grouped it, into nine subcategories because some of individual cropland types, as classified by the remote sensing analysis, comprise a small area and share characteristics with other systems so they were aggregated into some general grouping. The nine subcategories of cropland in this study including rice, sugarcane, cassava, para rubber, eucalyptus, orchard, horticulture, other annual crops, and other perennial crops.

Grassland in the study area was classified into two groups including grassland and shrubland. Settlement category was grouped into five subcategories including paved over land (houses, commercial buildings, factory, gas station, institutional land), city forest (villages which have woodlands), city park garden (recreation area and resort), grassland with some buildings (cattle farm house and cemetery), and landfill (garbage dump). Wetland category was classified into water area, in this case, it does not have a subcategory.

Biomass management

The IPCC methodology required three categories of activity data for the evaluation of biomass management, including fuelwood removals, wood removals or harvest, and woody biomass changes in each Gain-Loss category system. For each land use conversion, the methods also require information on previous land use sub-categories for the area of land involved in a particular land use and carbon stocks changes. In this study it is assumed that all the area converted from forest was cleared without burning.

Crop residue management

The amount of crop residues that are retained on the field vs removed (e.g. for fodder, fuel or other purpose) has an impact on soil C stocks. The estimated residue management practices for each of the major annual crops gives in Table 3.1.

Table 3.1: Values defining residue management practices or each crop, given as percentage of total residue production.

Crop	Burned (%)	Grazed or Collected (%)	Retained (%)	Reference
Rice	-	76	24	Papong et al. (2004)
Sugarcane	20	75	5	Rípoli et al. (2000)
Cassava	-	50-75	25-50	Munyahali et al. (2017)
Other annual crops	-	70	30	Papong et al. (2004)

Rice system

Water management in rice has a major impact on soil methane emissions. There are two main types of management systems in the Kalasin province including non-flooded preseason less than 180 days with rainfed and deep water rice making up 81% of the total area and flooded pre-season 30 days in irrigated area making up around 19%.

Soil carbon

Annual crop cultivation in the Kalasin province was assumed to use full tillage or conventional tillage. The farmers in this study area typically use chemical fertilizer, manure, and compost in the cultivation area. Therefore, the practice that affects carbon input in this study area is nitrogen fertilizer with organic amendments. Grassland management was categorized into three groups; improved grassland (pasture and abandoned paddy field), improved grassland with multiple practices (grassland plantation including turf grass), and nominal or native grassland (shrubland, grass, and abandoned area).

Land use change

From our land use conversion analysis between 2006 and 2015, there were 36 land use conversion classes (including the case of a no-change class) in the study area. However, only 14 land conversions classes, accounting for 99.13% of the area of the Kalasin province (Table 3.2), were used since the remaining 20 land conversion classes total less than 0.9% of the study area.

Table 3.**2:** The land-use conversions, which were considered to evaluate GHG emissions in the Kalasin province, Thailand from 2006 to 2015.

Land use conversion	**Abbreviation**	**Area (ha)**	**% of total land in Kalasin**
Forestland remaining forestland	FF	82,702	11.99
Forestland converted to cropland	FC	9,301	1.35
Forestland converted to grassland	FG	1,992	0.29
Forestland converted to settlement	FS	1,182	0.17
Cropland remaining cropland	CC	488,179	70.77

Cropland converted to forestland	CF	5,697	0.83
Cropland converted to grassland	CG	6,682	0.97
Cropland converted to settlement	CS	4,324	0.63
Grassland remaining grassland	GG	5,701	0.83
Grassland converted to forestland	GF	1,279	0.19
Grassland converted to cropland	GC	4,347	0.63
Settlement remaining settlement	SS	29,494	4.28
Wetland remaining wetland	WW	41,007	5.94
Wetland converted to cropland	WC	1,967	0.29

BOUNDARY OF THE STUDY AREA AND INVENTORY EMISSIONS

It is important to set the boundaries of the GHG inventory analysis. The total emissions of GHG and soil carbon stocks from the Kalasin province, Thailand that we estimated include seven sources; (1) biomass carbon stocks from land use and land use conversions; (2) carbon stocks from mineral soils; (3) CH_4 emissions from rice cultivation; (4) CH_4, N_2O, NO_x, and CO emissions from crop residues burning in the cropland; (5) direct N_2O emissions from crop residues and mineral N fertilizers; (6) indirect N_2O emissions from crop residues and mineral N fertilizers; and (7) CO_2 emissions from urea fertilizers. This study focused on the emissions and removals of CO_2 for the AFOLU sector, which was evaluated form each land use and land use change type. However, the other land category and livestock management such as CH_4 emissions from animal waste management and enteric fermentation were not considered in this study. Moreover, CO_2, N_2O, and CH_4 emissions from fossil fuels combustion also were not included in this study. The annual carbon stock change equation from the 2006 IPCC Guidelines was used (Eq. 1). The total of carbon stock changes in forestland (ΔC_{FL}), cropland (ΔC_{CL}), grassland (ΔC_{GL}), wetlands (ΔC_{WL}), and settlements (ΔC_{SL}) comprise the total annual carbon stock change in the AFOLU sector.

Since CO_2, N_2O, CH_4, and other non-CO_2 emissions have different units, they need to be converted to CO_2 equivalents which are based on the 100-year time horizontal global warming potentials (GWPs) relative to CO_2 from the IPCC Fifth Assessment Report: AR5 (2013). Therefore, 1, 265, and 28 are the GWPs of CO_2, N_2O, CH_4 respectively with the 100-year time span (IPCC, 2013).

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} \qquad \text{(Eq. 1)}$$

BIOMASS CARBON STOCKS

The generic decision tree for identification of the appropriate tier was used to estimate carbon stocks in biomass in land use category (IPCC Guideline, 2006). In this study, there was no detailed data available to estimate forest carbon stock changes using dynamic models, and there was no specific biomass data and emission/removal factors available for Thailand. However, there was aggregate data on biomass growth and loss available. Therefore, the Tier 1 method was used for this study area (IPCC Guideline, 2006).

The method required data on land use categories, area by climate, area by ecological zone, area by soil type, land use categories and subcategories. The biomass carbon stocks in each land conversion were subdivided into land use subcategories and type of crop/tree, each having different stock change factors. The uncertainties for default emission factors are provided in the IPCC guidelines (IPCC Guideline, 2006). Moreover, the previous land use subcategories for each land conversion were also required in the method. For example, in the case of a forest to cropland (e.g. cassava) conversion, the method requires information on attributes of the forestland that was converted. The ALU software was used to estimate the annual change in carbon stock in biomass (dCB) in tonne C per year with 95% confidence interval, the annual increase in biomass carbon stocks, the initial change in carbon stocks due to land conversion, and the annual decrease in carbon stocks due to biomass losses. When using, the Tier 1 method, changes in woody biomass stocks in the grassland remaining grassland, settlement remaining settlement, and wetland remaining wetland are assumed to be zero, because woody biomass in these systems is often negligible and data are stocks are typically lacking (IPCC Guideline, 2006).

Both land remaining in the same land and land converted to another land use used Gain-Loss method to estimate annual carbon stock in woody biomass (Eq. 2). This method requires biomass carbon gains (C_G) including biomass growth in above-below ground parts. Moreover, biomass carbon losses (C_L) including wood removals, timber harvest, and natural disturbances (e.g. there was wildfire in this study). Therefore, total biomass carbon losses are subtracted from biomass carbon gains to get the change in biomass carbon stock in biomass per year.

$$C_B = C_G - C_L \quad \text{(Eq. 2)}$$

SOIL CARBON STOCK CHANGES

Since this study used the Tier 1 method to estimate soil carbon stocks (ΔC_{soils}), the net flux for inorganic carbon stocks (e.g. from liming) was not estimated due to lack of data. Therefore, the annual carbon stock change in the soils in the Kalasin province is determined by organic carbon stocks in mineral soils minus annual carbon loss from drained organic (e.g. peat) soils (Eq. 3).

$$\Delta C_{soils} = \Delta C_{mineral} - \Delta L_{organic} \qquad \text{(Eq. 3)}$$

METHANE EMISSIONS FROM RICE CULTIVATION

CH_4 emissions evaluation in the rice paddy in the Kalasin province, Thailand used CH_4 emissions from rice cultivation from the 2006 IPCC guidelines (Eq. 4). The CH_4 emissions from paddy field are calculated by multiplying daily emission factors ($EF_{i,j,k}$) over the duration of the rice cultivation period ($t_{i,j,k}$) and all rice harvest area ($A_{i,j,k}$). In this study area, the rice paddy was classified into two rice paddy management systems with the details of water regime management before and during cultivation in the Table 3. The paddy field applied with manure 3.75 tonnes per hectare or chemical fertilizer (N:P:K); 172 kg 16-16-8 ha^{-1} in the first phase of cultivation and 29 kg urea N ha^{-1}in the second phase (Rice Research and Development Office, Thailand, n.d.).

$$CH_4 \text{ Rice} = \Sigma_{i,j,k} (EF_{i,j,k} \bullet t_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6}) \qquad \text{(Eq. 4)}$$

Table 3.3:The rice cultivation water management systems in the Kalasin, Thailand applied with 3.75 tonnes manure ha^{-1}.

Water regime before cultivation	**Water regime during cultivation**	**Percent of the rice field**
Non-flooded pre-season <180 days	Rainfed and deep water	92%
Flooded pre-season > 30 days	Irrigated	8%

NON-CO_2 GREENHOUSE GAS EMISSIONS FROM BIOMASS BURNING (*CROP RESIDUES*)

Biomass burning that creates non-CO_2 greenhouse gas emissions include grassland burning, agricultural residues burning, burning of litter and harvest residues in forestland, burning following forest clearing and conversion to agriculture, and other types of burning (those resulting from wildfires) (IPCC Guideline, 2006). However, in this study, only non-CO_2 GHG emissions from crop residues burning was estimated. To evaluate the non-CO_2 GHG emissions from crop burning, the GHG emissions from the fire equation was used (Eq. 5). Since Tier 1 methodology was used for the evaluation, the default data including combustion factor (C_f), emission factor (G_{ef}), and mass of fuel available for combustion (M_B) were used from the 2006 IPCC guidelines (IPCC Guideline, 2006).

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3} \qquad \text{(Eq. 5)}$$

DIRECT N_2O EMISSIONS FROM CROP RESIDUES AND MINERAL N FERTIZERS

There are many N sources which can be considered for evaluating direct N_2O emissions from managed soils. These include synthetic N fertilizers, organic N applied as fertilizer, urine and dung N deposited on pasture by grazing animals, N in crop residues, N mineralization associated with loss of soil organic matter resulting from change of land use, and drainage of organic soils (IPCC Guideline, 2006). In this study we focused on the direct N_2O emissions estimation from N in crop residues (F_{CR}) and synthetic fertilizers (F_{SN}). Therefore, the annual direct N_2O-N emissions produced from managed soils is annual direct N_2O-N emissions from N inputs to managed soils (Eq. 6).

$$N_2O_{direct} = N_2O_{N\ inputs}$$

Where:

$$N_2O_{N\ inputs} = \{[(F_{CR}+F_{SN}) \bullet EF_1] + [(F_{CR}+F_{SN})_{FR} \bullet EF_{1FR}]\} \qquad \text{(Eq. 6)}$$

INDIRECT N_2O EMISSIONS FROM CROP RESIDUES AND MINERAL N FERTIZERS

Indirect N_2O emissions have two subsources: 1) the volatilization of soil N as NH_3 and NO_x, and N leaching and runoff from land. (IPCC Guideline, 2006). In this study we focus on the indirect N_2O emissions from N leaching/runoff of N land ($N_2O_{(L)}$-N) from crop residue inputs (F_{CR}) and synthetic fertilizer N applied (F_{SN}). Moreover, the indirect N_2O emissions from atmospheric deposition of N volatilized from managed soils ($N_2O_{(ATD)}$-N) was considered. The Tier 1 equations (Eq. 7-8) were used to estimate the emissions with default emission and partitioning factors and available data including fraction of synthetic fertilizer N that volatilizes as NH_4^+ and NO_3^- ($Frac_{GASF}$) and fraction of all N inputs ($Frac_{Leach\text{-}(H)}$).

$$N_2O_{(L)}\text{-}N = (F_{SN}+F_{CR}) \bullet Frac_{Leach\text{-}(H)} \bullet EF_5 \qquad \text{(Eq. 7)}$$

$$N_2O_{(ATD)}\text{-}N = (F_{SN} \bullet Frac_{GASF}) \bullet EF_4 \qquad \text{(Eq. 8)}$$

CO_2 EMISSIONS FROM UREA FERTILIZATION

Adding urea to soils can remove CO_2 from the atmosphere in urea industrial production process. Urea is transformed into NH_4^+, OH^-, and HCO_3^- in the existence of water and urea enzymes which is similar to the soil and lime or bicarbonate reaction. Annual CO_2 emissions from urea application (CO_2-C Emission) estimated from the emission factor (EF) multiply by annual amount of urea fertilization (M) (Eq. 9).

$$CO_2\text{-C Emission} = M \bullet EF \qquad \text{(Eq. 9)}$$

RESULTS AND DISCUSSION

BIOMASS CARBON STOCKS FROM LAND USE AND LAND USE CHANGE

The net woody biomass carbon stock change associated with land use and land use change for 2015 in this study area was a loss of 1,061 Gg CO_2 eq. (Table 3.4). The largest loss of biomass carbon was in forestland converted to the cropland category, amounting to 1,143 Gg CO_2 eq. In addition, other land use conversions of forest, FG, FS, CG, and CS, also yields losses of biomass carbon stocks. However, there were some land use and land use conversion categories which gained biomass carbon stocks including FF, CF, CC, GF, GC, and WC. In this study area, forestland remaining forestland had the greatest gain in biomass carbon stocks (477 Gg CO_2 eq.), which is similar to the study of Pan et al. (2011), they reported that the largest of global carbon sink is forest. Interestingly, when considering the gain or loss of biomass carbon stocks on a per hectare basis, it was found that the FS was the largest biomass carbon loss by 252 tonnes CO_2 eq. ha^{-1} (Fig. 3.3). Following by the FG and FC, which were 219 and 123 tonnes CO_2 eq. ha^{-1}, respectively. Moreover, as shown in the Figure 3.3, the forest conversion was the major of biomass carbon stock loss in the study area. Bryan et al. (2010) and Latif et al. (2015) reported that the biomass volume and carbon stock losses in tropical forest and rainforest because of deforestation. As can be seen in the Figure 3.3, the conversion associated with the largest gain in biomass carbon stocks was WC, and this is associated with a greater aboveground biomass of plants under cropping system than wetlands. From Fig. 3.3, it is clear that logging activities are the major cause of biomass carbon stock losses and that growing plants can cause increasing of biomass carbon stocks.

Table 3.4**:** Change in biomass carbon stocks in tonne CO_2 equivalent for 2015 in each land use and land use change categories, Kalasin, Thailand. (1 Gg = 1000 tonnes) Negative sign (-) means biomass carbon stock loss.

2015 2006	Forest	Cropland	Grassland	Settlement	Wetland
Forest	477,377	-1,142,987	-436,834	-298,031	
Cropland	10,702	426,080	-55,408	-110,851	
Grassland	5,918	29,743			
Settlement					
Wetland		33,372			

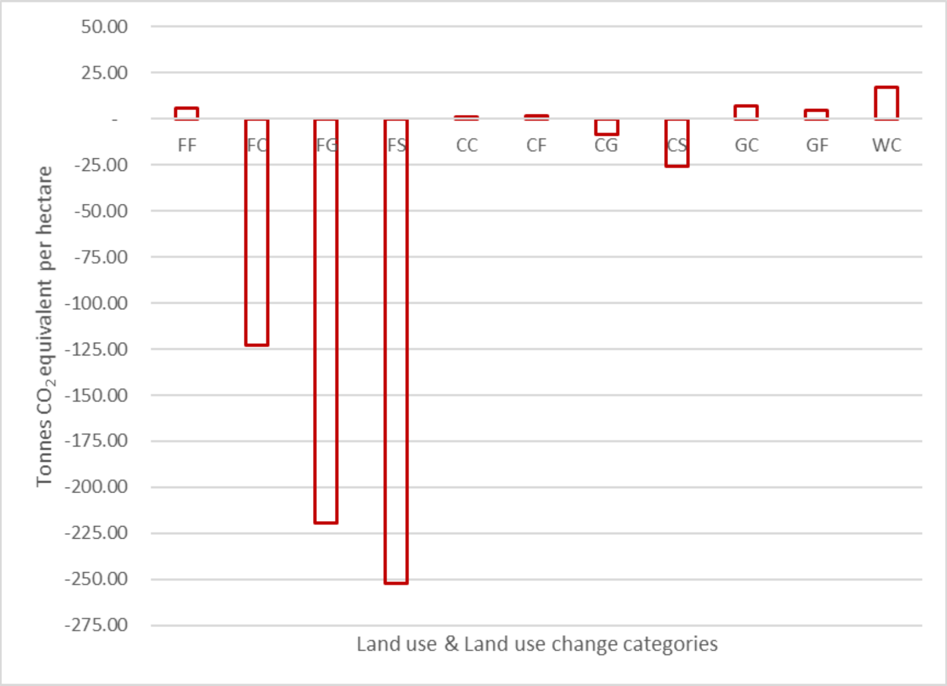

Figure 3.3**:** Change in biomass carbon stocks in tonne CO_2 equivalent per hectare for 2015 in each land use and land use change categories, Kalasin province, Thailand.

CARBON STOCK CHANGES FROM MINERAL SOILS

According to the figure 3.4, carbon stock changes in soils are estimated from the soil carbon stock changes in mineral soils and annual carbon losses from drained organic soils. Since the soil types in this study area do not include organic soils, the organic soil carbon loss due to drainage in the study area was assumed as zero. Therefore, only carbon stock changes from the mineral soils were estimated in the Kalasin province using 20 years which is the default time period for transition between equilibrium soil organic carbon stock values. The soil carbon stock change in unchanged land uses were assumed to be zero since there was no change in the land use and the soil carbon stocks were stable. The total of mineral soil carbon stock changes from 2006 to 2015 in this study area was a loss of soil carbon stocks by 7,607 tonnes CO_2 eq. The soil carbon stock changes in the mineral soils of each land use conversion categories in this study are shown in Table 3.5. The highest mineral soil carbon loss in this study area was from forest converted to cropland with full tillage management. The second highest GHG emission from the mineral soil in this study area was the conversion from wetland to cropland with full tillage practice. As can be seen on Table 3.5, lands that were converted to croplands and urban areas resulted in a loss carbon from the soils. Similar to Guo and Gifford (2002), Don et al. (2011) found that there were 25-42% soil carbon stock losses associated with forest conversion to cropland. However, the majority of mineral soil carbon stock changes in the Kalasin province was associated with the conversion from cropland to forest, followed by cropland transferred to grassland. It is clear that cropland with full tillage is an important contributor to soil carbon stock losses. According to conventional tillage caused a loss in soil carbon stocks, while no-till management system increased soil carbon stocks.

Table 3.5: The soil carbon stocks and soil carbon stock changes from 2006 to 2015 in each land use change category, Kalasin, Thailand. Negative sign (-) means biomass carbon stock loss.

LUC category	**SOC 2006 (tonnes C)**	**SOC 2015 (tonnes C)**	**SOC change (tonnes CO2 eq.)**	**SOC change (tonnes CO2 eq. ha^{-1})**
FC	483,010	408,280	-13,700	-1.47
FG	112,864	111,865	-183	-0.09
FS	59,437	42,021	-3,193	-2.70
CF	215,702	287,031	13,077	2.30
CG	263,663	315,304	9,467	1.42
CS	192,940	179,916	-2,388	0.55
GF	54,562	68,453	2,546	2.00
GC	211,890	186,327	-4,703	-1.08
WC	169,139	122,606	-8,531	-4.38

CH_4 EMISSION FROM RICE CULTIVATION

The net flux of CH_4 emissions for 2015 from the rice paddy areas in the Kalasin province, Thailand was 1,205 Gg CO_2 eq. There were two rice management systems in the study area: 1) flooded at pre-season more than 30 days with an irrigated system during the cultivation, 2) and non-flooded pre-season less than 180 days with rainfed and deep water regime during the cultivation period. It was found that the CH_4 emissions from the flooded at pre-season with irrigated water regime has a higher daily CH_4 emissions factor for rice cultivation than the non-flooded before cultivation with rainfed and a deep water system. As a result, based on the CH_4 emissions per hectare, the CH_4 emissions from the rice that was flooded before the growing season had over five times higher than the CH_4 emissions than the rice that was not flooded at pre-season (Table 3.6). However, 92% of the rice paddy in this province was the non-flooded before cultivation with rainfed and deep water. Therefore, the total CH_4 emissions from the non-flooded before cultivation was higher.

Similar to our results, Yagi et al. (1996) reported that a continuously flooded in rice paddy in Japan emitted CH_4 to the atmosphere higher than the rice field with intermittently drained system. Moreover, Sass et al. (1992) studied CH_4 emissions from the four water systems in the rice paddy in Texas, they reported that the lowest of CH_4 emissions from the paddy field is the normal flood with multiple drainage aeration system and the late flood water system, which is 76 days after planting, is the highest CH_4 emissions.

Table 3.6**:** The CH_4 emissions from rice paddy for 2015 in the Kalasin province, Thailand

Pre-cultivation water regime	**Cultivation water regime**	**tonnes CO_2 eq.**	**tonnes CO_2 eq. ha^{-1}**
Flooded pre-season > 30 days	Irrigated	389,480	17.26
Non-flooded pre-season < 180 days	Rainfed and deep water	816,200	3.15

CH_4, N_2O, NO_X, AND CO EMISSIONS FROM BIOMASS BURNING **(***CROP RESIDUES***)**

The net flux of CH_4 and N_2O emissions from the crop residues burning for 2015 in the study area was 12 Gg CO_2 eq. Non-CO_2 emissions (CH_4, N_2O, NO_x, and CO) and is presented in Table 3.7.

Table 3.7**:** The CH_4, N_2O, NO_x, and CO emissions from biomass burning (crop residues) in the Kalasin province, Thailand

Non- CO_2	**Quantity**	**Units**
CH_4	9.48	Gg CO_2 eq.
N_2O	2.33	Gg CO_2 eq.
*NO_x	0.31	Gg NOx
*CO	11.53	Gg CO

*Total Greenhouse Gas Emissions does not include CO or NOx

DIRECT N_2O EMISSIONS FROM CROP RESIDUES AND SYNTHETIC FERTILIZERS

The N_2O emissions from managed soils which was estimated from N fertilizer and crop residue inputs in the croplands of the Kalasin province, Thailand. The total of direct N_2O emissions from N inputs was 388 Gg CO_2 eq. The direct N_2O emissions from the crop residues in each crop types are shown in Table 3.8, and Table 3.9 shows the direct N_2O emissions from the synthetic N fertilizer inputs. As can be seen in Table 3.8, sugarcane emitted the highest amount of N_2O from crop residues. In sugarcane, there is often burning before harvest in Thailand and Brazil and sugarcane produced a large amount of crop residues (Yuttiham et al., 2011; Rípoli et al., 2000). As a result, sugarcane was the major of cropland to emit N_2O into the atmosphere. In Table 3.9, urea is the largest component of fertilizer application in the study area because there is a big amount of urea application for rice cultivation

Table 3.8**:** The direct N_2O emissions from crop residue in the Kalasin province, Thailand

Direct N_2O emissions	**Emissions (tonnes CO_2 eq.)**
Cassava	11,194
Rice paddy	19,300
Sugarcane	293,105
Other crops	11

Table 3.9**:** The direct N_2O emissions from the synthetic fertilizer in the Kalasin province, Thailand

Direct N_2O emissions	**Emissions (tonnes CO_2 eq.)**
Urea	50,990
Ammonium Sulphate	5,798
Diammonium Phosphate	4,970
Monoammonium Phosphate	2,639

INDIRECT N_2O EMISSIONS FROM CROP RESIDUES AND SYNTHETIC FERTILIZERS

The N_2O emissions from managed soils was also estimated from leaching or runoff in the croplands and N volatilized from atmospheric deposition of the Kalasin province, Thailand. The total of indirect N_2O emissions from the leaching/runoff and atmospheric deposition was 94 Gg CO_2 eq. The indirect N_2O emissions from the leaching/ runoff in each crop type and N fertilizers are shown in the Table 3.10. The indirect N_2O emissions from atmospheric deposition of N volatilized from managed soils is shown in Table 3.11.

Table 3.10**:** The indirect N_2O emissions from leaching/runoff; crop residues and N fertilizers in the Kalasin province, Thailand

Indirect N_2O emissions	**Emissions (tonnes CO_2 eq.)**
Cassava	2,519
Rice paddy	4,343
Sugarcane	65,949
Other crops	3
Urea	11,473
Ammonium Sulphate	1,305
Diammonium Phosphate	1,118
Monoammonium Phosphate	594

Table 3**.**11**:** The indirect N_2O emissions from atmospheric deposition; N volatilised in the Kalasin province, Thailand

Direct N_2O emissions	**Emissions (tonnes CO_2 eq.)**
Urea	5,099
Ammonium Sulphate	580
Diammonium Phosphate	497
Monoammonium Phosphate	264

CO_2 EMISSIONS FROM UREA FERTILIZATION

The total CO_2 emissions from urea is based on the amount of urea used and the emissions factor. Urea fertilizer is used in rice paddy which is the largest section of cropland in the Kalasin province for both 2006 and 2015. Urea applied was about 63 kg/ha in the rice fields in this study area (Department of Agriculture of Thailand, 2005). Moreover, other nitrogenous fertilizers have urea as their N component including 15-15-15 fertilizer which was used for cassava and sugarcane and 16-16-8 fertilizer which was used for rice paddy. Therefore, the proportion of urea in the fertilizer solution was estimated. The total CO_2 emissions from urea fertilization was 20 Gg CO_2 eq in the Kalasin province.

CONCLUSION

The total net flux of the GHG emissions in the Kalasin province from 2006 to 2015 was 2,788 Gg CO_2 eq. yr^{-1}. Figure 3.4 shows the GHG emission by Gg CO_2 eq. yr^{-1} from the emission sources including biomass carbon losses, soil carbon losses, non-CO_2 emissions from biomass burning, CH_4 emission from rice paddy, and direct and indirect N_2O emissions from crop residues in the study area.

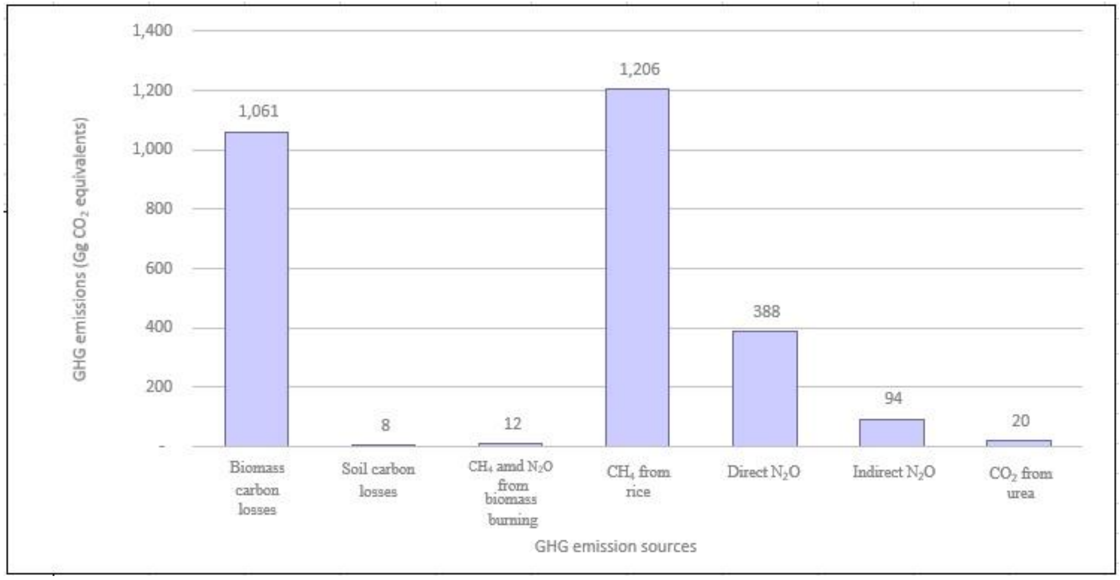

Figure 3.4**:** Annual GHG emission from each emission source in the Kalasin province.

As can be seen in the figure 3.4, the largest GHG emission source in the inventory year was the CH_4 emissions from rice cultivation, followed by the biomass carbon losses. It is clear that rice paddy is the largest source of GHG emissions in this province due to the large area of rice cultivation in the Kalasin province and that CH_4 has 28 times more warming impact of CO_2 over a hundred year of time scale.

The major biomass carbon stock losses were from deforestation, and included forest converted to urban area, forest converted to grassland, and forest converted to cropland. As for biomass carbon losses, the major mineral soil carbon losses also came from deforestation (forest converted to cropland). Since most farmers of the Kalasin province, Thailand are still using conventional tillage management in their cropland, there is a high level of soil disturbances. Therefore, there were high soil carbon stocks losses in lands converted to cropland. In addition, urea fertilizer is used for crop cultivation in the Kalasin province including rice, cassava, sugarcane. Therefore, there are CO2 emissions from urea application which make up around 20 Gg CO_2 eq in this province.

CH_4 emissions from the flooded at pre-season with irrigated water regime in the rice paddy area of the Kalasin province had ability to produce higher GHG emissions, over five times, compared to the non-flooded before cultivation with rainfed and a deep water system. Since anaerobic condition influences CH_4 production, the non-flooded before cultivation with rainfed and a deep water system might be the optimal option for rice cultivation in this area. However, Chen et al. (1997) said that N_2O would be emitted during non-flooded period of rice cultivation. Most of direct and indirect N_2O emissions from leaching/runoff and atmospheric deposition of crop residues and N fertilizers in this province came from cash crop cultivation, especially sugarcane. Since N fertilizer increases crop residues and soil microbial activity, the N_2O productions from denitrification and nitrification by the soil microbial is increased. However, Nitrate (NO^{-3}) addition affects to decrease CH_4 emissions (Yu et al., 1997). So, selecting an option to reduce GHG emissions in this area, particularly CH_4 and N_2O emissions need to be considered. According to Cai et al. (1997), N fertilizers and water management system in rice field affected CH_4 and N_2O emissions, N_2O emissions increased with increasing of N input, however, CH_4 emissions increased during flooding. They went on to say that using urea treatments emitted N_2O to the atmosphere lower than using ammonium sulphate treatments at the same amount. Therefore, it is essential to estimate the unifying effects of water system and N input for GHG mitigation in rice fields.

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APPENDIX

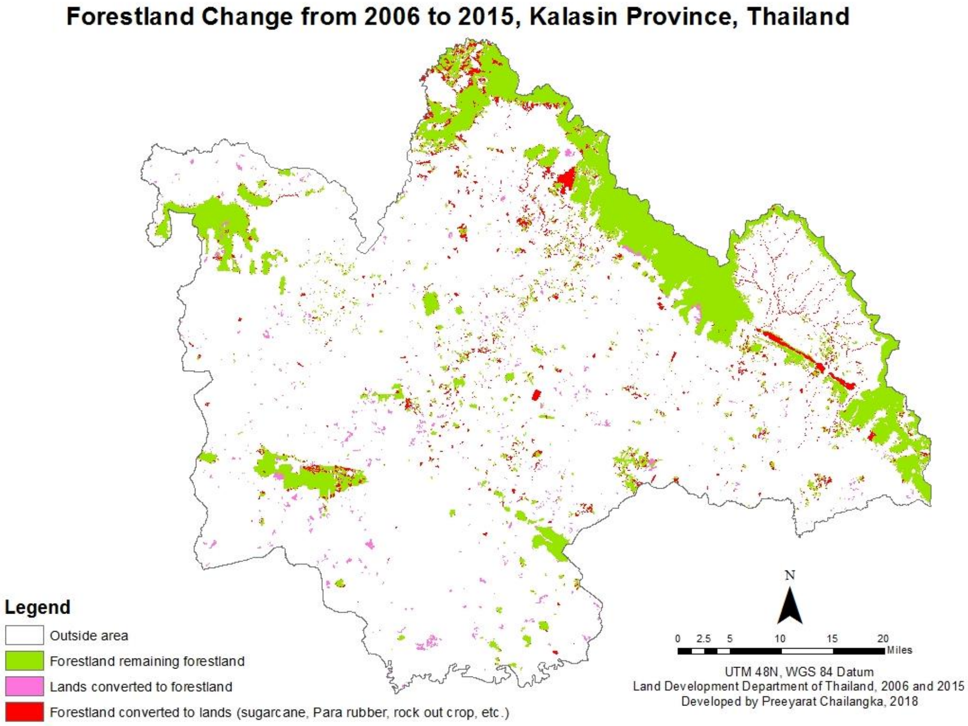

Figure A.1: Map of forestland change in the Kalasin province, Thailand between 2006 and 2015.

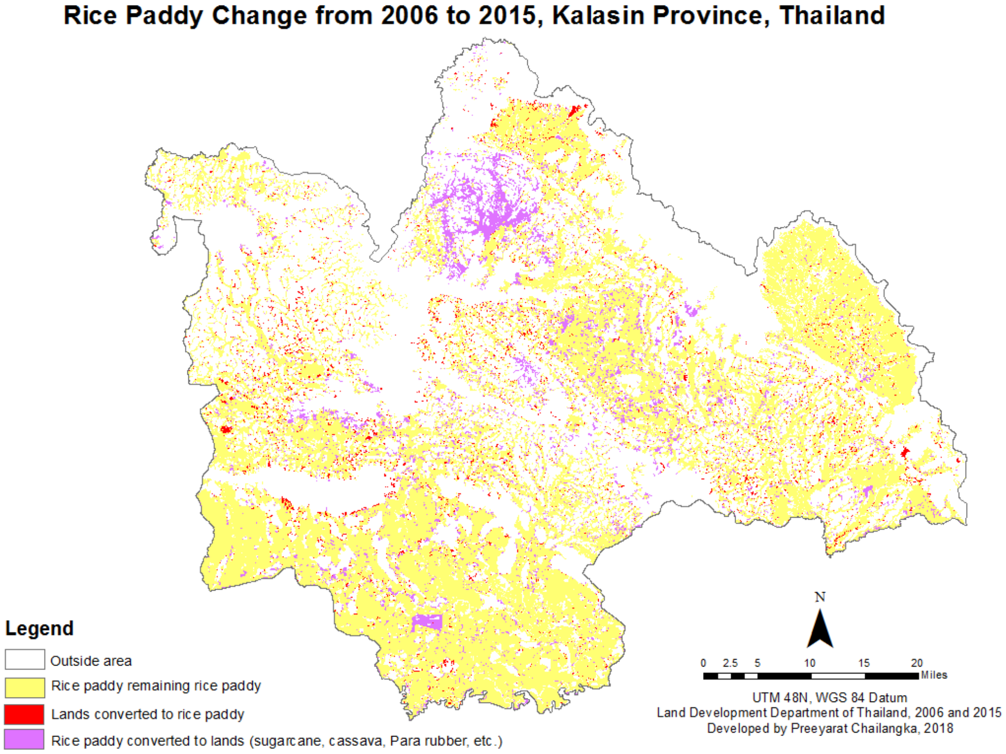

Figure A.2: Map of rice paddy change in the the Kalasin province, Thailand between 2006 and 2015.

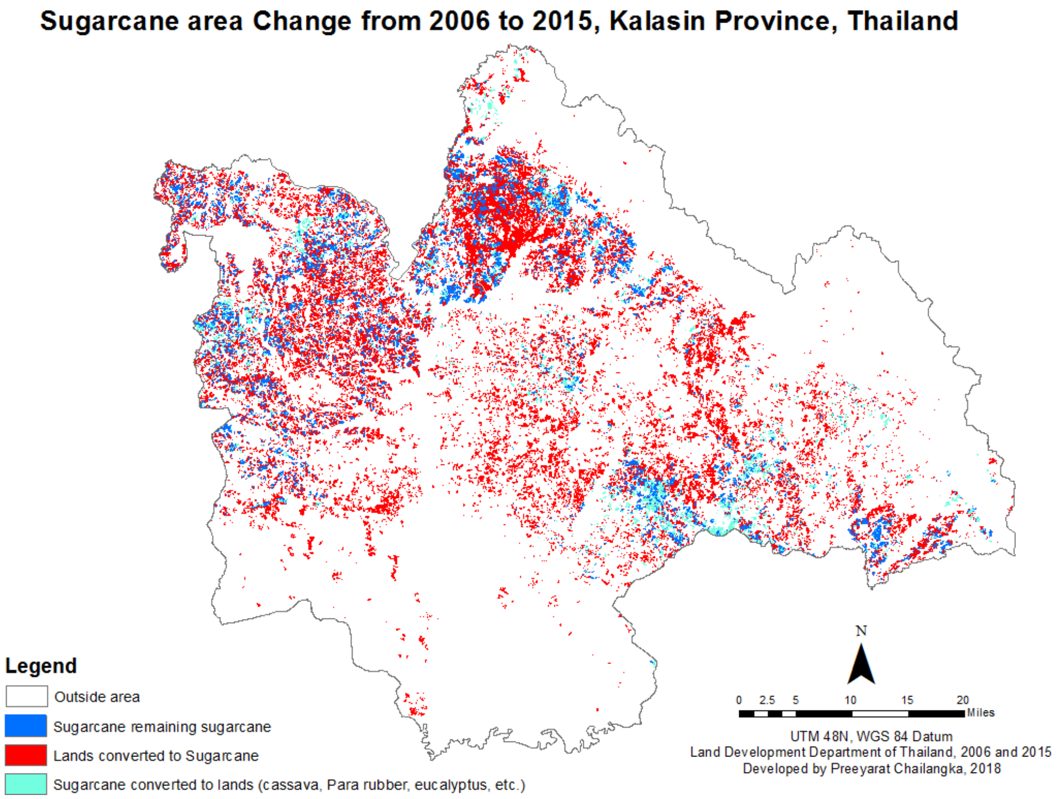

Figure A.3**:** Map of sugarcane area change in the Kalasin province, Thailand between 2006 and 2015.

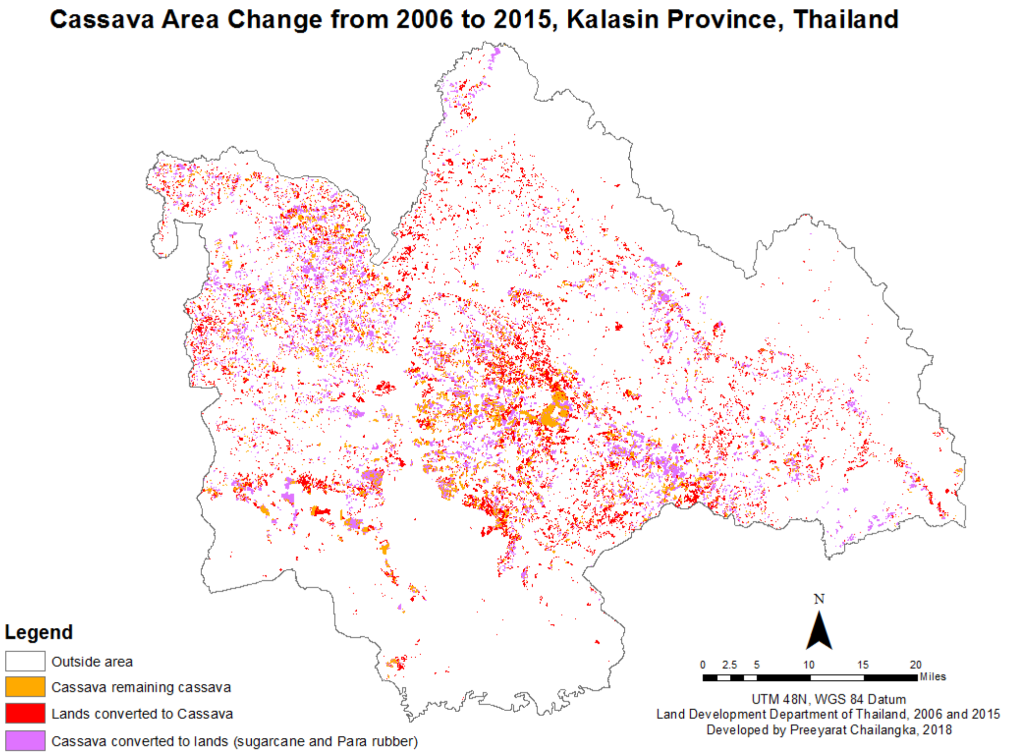

Figure A.4**:** Map of cassava area change in the Kalasin province, Thailand between 2006 and 2015.

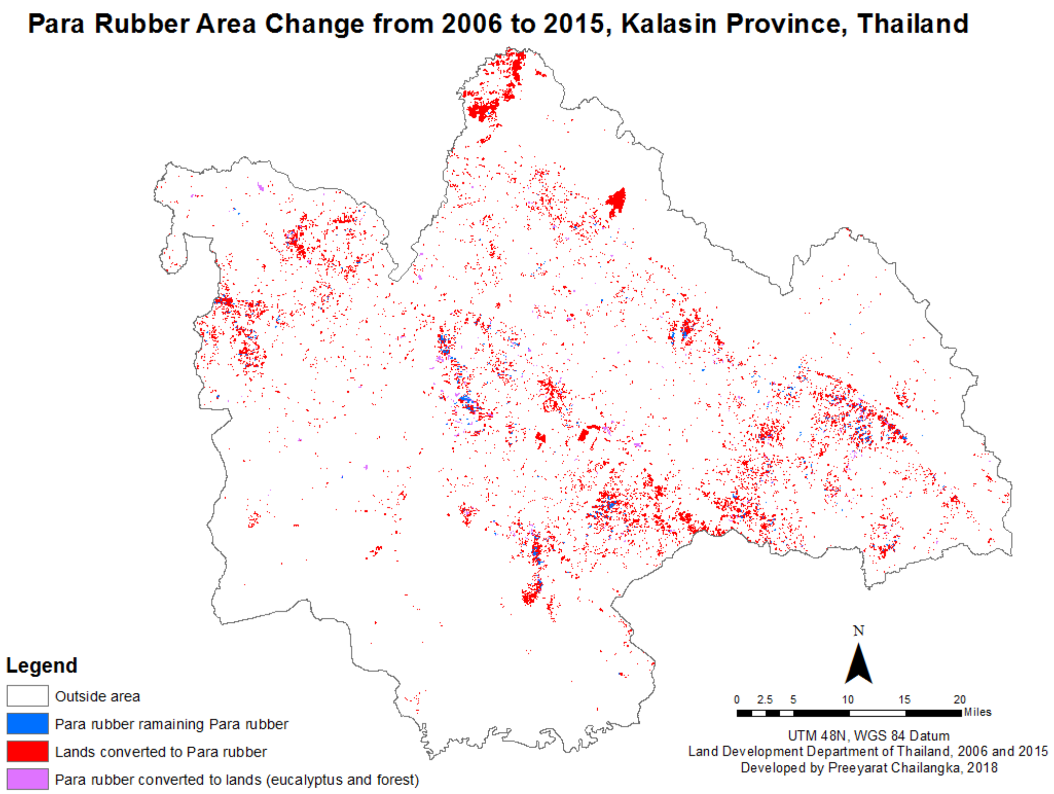

Figure A.5**:** Map of para rubber area change in the Kalasin province, Thailand between 2006 and 2015.

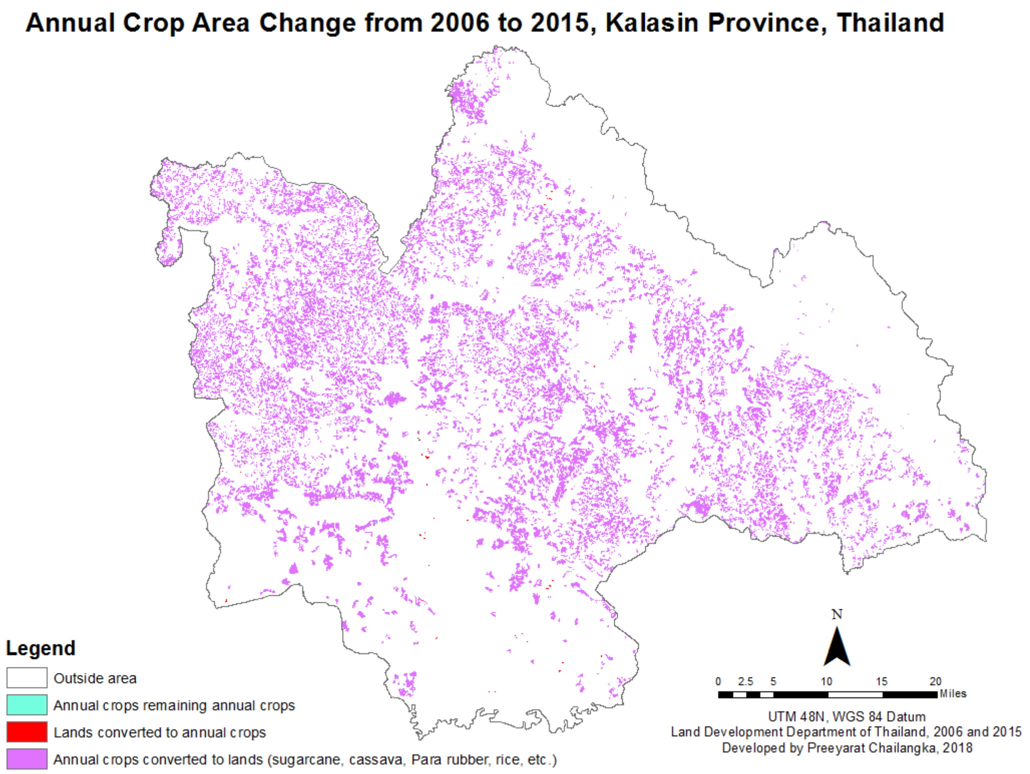

Figure A.6**:** Map of annual crops area change in the Kalasin province, Thailand between 2006 and 2015.