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Impacts of Land Use Changes on Carbon Stocks, Greenhouse Gas, and Carbon Economic Value of Agriculture, Forestry and Other Land Use (AFOLU) Sector in Coastal Area of Yi San Sub-District, Samut Songkhram Province, Thailand between 2001 and 2015

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Abstract

The objectives of this research were to 1) study changes in land use of Agriculture, Forestry and Other Land Use (AFOLU) sector using GIS application as a tool for accounting land use type area for each given periods, 2) to estimate the amount of carbon stocks, and carbon dioxide emissions and removals from changes of 6 land use types (mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land) which were evaluated under the standard method of the 2006 IPCC Guideline for National Greenhouse Gas Inventories, and 3) to evaluate the economic value of carbon dioxide based on existing carbon price in California Carbon Market. The result showed that between 2001 and 2015 in Yi San Sub-district, Samut Songkhram Province, different types of land use were changed from aquaculture to mangrove forest (974.37 ha), followed by mangrove forest to aquaculture (770.75 ha), respectively. Mangrove forests increased in carbon stocks due to biomass growth of 50,730.63 tC and the large proportions of decrease in carbon stocks in biomass were from aquaculture land as -21,735.14 tC. The estimation of total carbon dioxide emissions was +123,043.83 tCO_2 and total carbon dioxide removals were -190,409.73 tCO_2. The land use with the highest carbon dioxide emission was the aquaculture land (+81,696.64 tCO_2), followed by the grassland (+35,058.26 tCO_2) and settlements (+5,509.30 tCO_2), respectively. The land use with the highest amount of carbon dioxide removal was the mangrove forest (-186,012.28 tCO_2), followed by the cropland (-2,257.41 tCO_2) and grassland (-2,140.04 tCO_2), respectively. The highest gain of economic value from CO_2 removals was the mangrove forest (2,808,785.43 USD) followed by cropland (22,314.48 USD). The highest economic loss from CO_2 emissions was the aquaculture land (1,233,619.26 USD) followed by the grassland (497,065.12 USD) and settlements (83,190.43 USD), respectively. As a result, those land use changes can reduce global warming potential (GWP) up to -67,365.90 tCO_2e and increase the net total carbon economic value as 1,017,225.09 USD.

Keywords: Land Use Changes; Carbon Stocks; Carbon Economic Value; AFOLU Sector; Coastal Area; Samut Songkhram Province; Thailand

1. Introduction

Global warming and climate change has been widely recognized as a major global issue as it threatens to alter the natural environment, disrupt the well-being of society, and deter economic development. (IPCC, 2007). The greenhouse gases concentrations in the atmosphere have been proportionally emitted from the human activities as shown in the changes of land use pattern (IPCC, 2006). The Agriculture, Forestry and Other Land Use (AFOLU) sector plays a central role for food security and sustainable development, it is one of the four major sources (energy sector, industrial processes and product use sector, agriculture, forestry and other land use sector, and waste sector) of GHGs, particularly of carbon dioxide (CO_2) (IPCC, 2006). At a global scale of GHGs emissions by economic sector, the AFOLU sector is the largest emitting sector after the energy sector that accounted for 24% and 35%, respectively, of the total emissions (IPCC, 2014), but that if no further mitigation measures and technical efficiency improvements are implemented, future emissions may further increase by up to 30% by 2050 (Tubiello *et al*., 2014).

Between 1990 and 2005, Thailand had the 24th largest greenhouse gas emissions in the world, the 6th in Asia, and the 2nd in Southeast Asia. The highest greenhouse gas emission was the energy sector (73.13%), followed by the agriculture, forestry and other land use (AFOLU) sector (15.89%) and the industrial processes and product use sector (9.55%), respectively (The Joint Graduate School of Energy and Environment, 2012; The Thailand Research Fund, 2016). The AFOLU sector is unique among the sectors considered in this volume, since the mitigation potential is derived from both an enhancement of removals of GHGs, as well as reduction of emissions through management of land and livestock (IPCC, 2014).

The spatial inventory of CO_2 emissions and removals during 2007-2012 resulting from carbon stock change in biomass from land use and land use changes in Thailand based on the 2006 IPCC guidelines in the AFOLU sector. The result that Nan Province, Udon Thani Province and Bangkok was identified as a CO_2 emission source. The proportions of emissions in Nan were larger than CO_2 emission due to the conversions of forest land to the various types of cropland. In contrast, Surat Thani Province was considered as a carbon sink due to the large coverage of the forest land and perennial crop (Miphokasap, 2017).

Coastal areas play an important role in the global carbon cycle and therefore changes in land use could affect this role. Changes in land use influence the amount of carbon storage in vegetation and soil thereby either releasing CO_2 to, or removing it from, the atmosphere (Jong *et al*., 2010). In Thailand, mangrove forests are found mainly along the coastal area. Some local communities like those in Yi San Sub-district have developed a sustainable mangrove plantation for the purpose of charcoal production (Kridiborworn *et al*., 2012). Yi San Sub-district is located in the coastal zone of Amphawa District, Samut Songkhram Province, central Thailand. The first private mangrove forest plantation in Thailand started in Yi San in 1907 and it is known as a source of best quality mangrove charcoal production (Department of Marine and Coastal Resources, 2009). In 1987, the mangrove forest was approximately 50% which was degraded by intensive shrimp farming. When shrimp farming was unsuccessful, some locals turned to commercial mangrove plantation business as a new source of income. The mangrove areas have slightly increased recently (Department of Marine and Coastal Resources, 2009; Kridiborworn *et al*., 2012; Choosak, *et al*., 2016).

The objectives of this research are 1) to study changes in land use of Agriculture, Forestry and Other Land Use (AFOLU) sector 2) to estimate the amount of carbon stocks, carbon dioxide emissions and removals from changes of 6 land use types (mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land, and 3) to evaluate the economic value of carbon dioxide based on existing carbon price. The success of this study will lead to an awareness of stakeholders to recognize the impacts of greenhouse gas emissions from land use changes. The results shall also provide a database on greenhouse gas inventories, trend of greenhouse gas emissions and reduction of greenhouse gas from land use changes for policy makers and optimization of land use in coastal area during economic, social and environmental development in the future.

2. Materials and Methods

2.1 Study site

Yi San Sub-district (centered at 13° 16′-13° 19′ N 99° 52′-99° 56′ E) is located in the coastal zone of Amphawa District, Samut Songkhram Province, central Thailand (Figure 1). The first private mangrove forest plantation in Thailand started in Yi San in 1907 and it is known as a source of best quality mangrove charcoal production (Department of Marine and Coastal Resources, 2009). Local people were dependent on these forests for goods and services such as aquaculture and charcoal production. Mangrove plantations of Rhizophora apiculata was once common (Community-Based Research Division, 2009; Ratanavilaisakul, 2010). In 1987, the mangrove forest was approximately 50% which was degraded by intensive shrimp farming. When shrimp farming was unsuccessful, some locals turned to commercial mangrove plantation business as a source of income. The mangrove areas have slightly increased recently (Department of Marine and Coastal Resources, 2009; Kridiborworn *et al*., 2012; Choosak, *et al*., 2016).

2.2 Research methodology framework

Data analysis and evaluation were divided into four main parts of accounting land use changes, changes in carbon stocks, the CO_2 emissions and removals, and the amount of economic value were illustrated in Figure 2.

2.2.1 Re-arranging land use categories and classification of land use changes based on the 2006 IPCC guidelines in the AFOLU sector

The spatial layers (scale 1: 50,000 in 2001 and scale 1: 25,000 in 2006, 2009, 2011, 2012, 2015) of land use categories which were interpreted from satellite image, aerial photo and ground survey operated by the Land Development Department (LDD, 2017) were used as the activity data source. However, five main land use categories (urban and built-up land, agricultural land, forest land, water body, miscellaneous) of LDD differ from those of the 2006 IPCC guidelines. Thus, it needs to re-arrange the land use categories to be consistent. The six land categories (forest land, cropland, wetlands, grassland, settlements, other land) based the 2006 IPCC guidelines were subdivided into land remaining in the same category and converted from one category

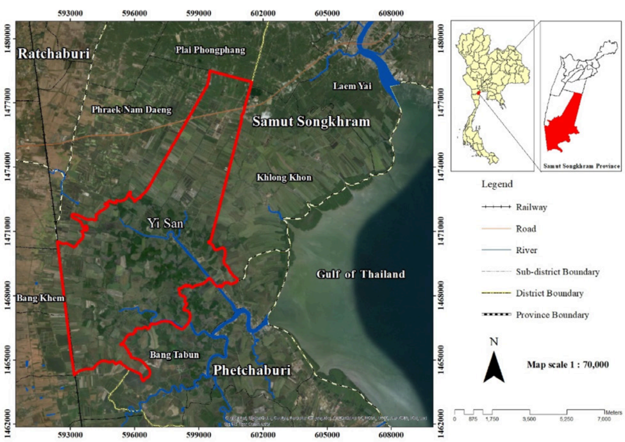

Figure 1. Study site in Yi San Sub-district, Samut Songkhram Province, Thailand
Source: Google Earth (2018)

Table 1. Land use categories and sub-categories based on the 2006 IPCC guideline

Land use categories	Sub-categories
Mangrove Forest	*Rhizophora apiculata*
Cropland	Paddy field
	Coconut
	Orchard
	Perennial
Grassland	Grass
	Scrub
Wetlands	River, Canal
	Natural water resource
Settlements	Village
	Road
	Institutional land
	Factory
	Poultry farm house
Other Land (Aquaculture Land)	Shrimp farm
	Mixed aquacultural land

to another. Each land category was further subdivided into sub-categories as illustrated in Table 1.

2.2.2 Estimation of annual carbon stocks in biomass changes

1) The emissions and removals of CO_2 for the AFOLU sector, based on change in ecosystem C stocks, are estimated for each land use categories including both land remaining in the same category and land converted to another land use for all subdivisions of land area category, carbon stock changes were separately calculated and summarized in six land use categories (IPCC, 2006) as shown in Equation (1).

$$\Delta C_{AFOLU} = \Delta C_{FL}+\Delta C_{CL}+\Delta C_{GL}+\Delta C_{WL}+\Delta C_{SL}+\Delta_{OL} \quad (1)$$

Where: ΔC is carbon stock change, AFOLU is Agriculture, Forestry and Other Land Use, FL is Forest Land (in this study FL is specified for Mangrove Forest), CL is Cropland, GL is Grassland, WL is Wetlands, SL is Settlements, and OL is Other Land (in this study OL is specified for Aquaculture Land)

2) Annual carbon stock changes in each land use type can be calculated using the Gain-Loss method. The Gain-Loss Method requires the biomass carbon loss to be subtracted from the biomass carbon gain as shown in Equation (2). Gain can be attributed to biomass growth at above and below ground components. Losses are categorized into wood harvesting, and losses from natural disturbances such as fire and flooding (IPCC, 2006).

$$\Delta C_B = \Delta C_G - \Delta C_L \quad (2)$$

Where: ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass) for each land sub-category, considering the total area, tC/yr, ΔC_G = annual increase in carbon stocks (Gain) due to biomass growth for each land sub-category, considering the total area, tC/yr, ΔC_L = annual decrease in carbon stocks (Loss) due to biomass loss for each land sub-category, considering the total area, tC/yr

2.2.3 Estimation of CO_2 emissions and removals

Convert C to CO_2 emissions and removals as shown in Equation (3).

$$CO_2 \text{ emissions and removals} = \Delta C_B \times \text{Conversion factor} \quad (3)$$

Where: ΔC_B = Annual carbon stock changes, Conversion factor = 44/12 (IPCC, 2006), Molecular weights: C = 12g/mol, O = 16 g/mol, CO_2 = 44 g/mol.

2.2.4 Evaluation of the economic value

Evaluation of the economic value of carbon dioxide in this study was based on existing carbon price in California Carbon Market as shown in Equation (4)

$$\text{Carbon Economic value} = CO_2 \text{ emissions and removals}(tCO_2e) \times \text{existing carbon price} \quad (4)$$

3. Results and Discussion

3.1 Distribution of land use and land conversions (ha) in Yi San Sub-district, Samut Songkhram Province, Thailand during 2001-2015

The main proportions of land use categories in Yi San Sub-district, Samut Songkhram Province were aquaculture and mangrove forest, respectively. The result showed that during 2009-2015, mangrove forest area continuously increased, while the area of aquaculture declined as illustrated in Table 2 and Figure 3. Distribution of land use in the past was consistent with data in Supplementary Table 1 and it was found that between 2006 and 2015, different types of land use especially aquaculture were changed to mangrove forest. Expansion of mangrove forest was driven by the failure of shrimp culture.

Between 2001 and 2015, the different types of land use in the study area were changed from aquaculture to mangrove forest (974.37 ha), followed by mangrove forest to aquaculture (770.75 ha), respectively, the proportion of land conversion to another land use was highest (21.59%) during the 2001-2006, followed by during 2006-2009 (14.15%), and 2012-2015 (6.03%), respectively. It can be concluded that mangrove forest expansion (approximately 204.91 ha) and reduction of shrimp farming area (approximately 353.87 ha) during the past 14 years led to a greater potential of land use as a source of carbon storage as illustrated in Figure 4 and in Supplementary Table 1.

3.2 Amount of carbon stocks (tC) and CO_2 emissions and removals (tCO_2) from land use and land use changes in Yi San Sub-district, Samut Songkhram Province, Thailand for each period during 2001-2015

In this study, the calculations of carbon stocks in biomass changes indicate that land uses in Yi San Sub-district, Samut Songkhram Province were as the carbon sink. This is mainly because of the large coverage of mangrove forest. The mangrove forest area, both land remaining and other land uses conversions to mangrove forest during 2001-2015 can increase in carbon stocks due to biomass growth with the total values of 50,730.63 tC. In contrast, during 14 years period, the loss of mangrove forest was mainly caused by the conversions to aquaculture which resulted in the large proportions of the decrease in carbon stocks in biomass with the values of -21,735.14 tC as illustrated in Figure 5 and in Supplementary Table 2.

Over the period 2001-2015, AFOLU, net total carbon dioxide emissions of Yi San Sub-district, Samut Songkhram Province were

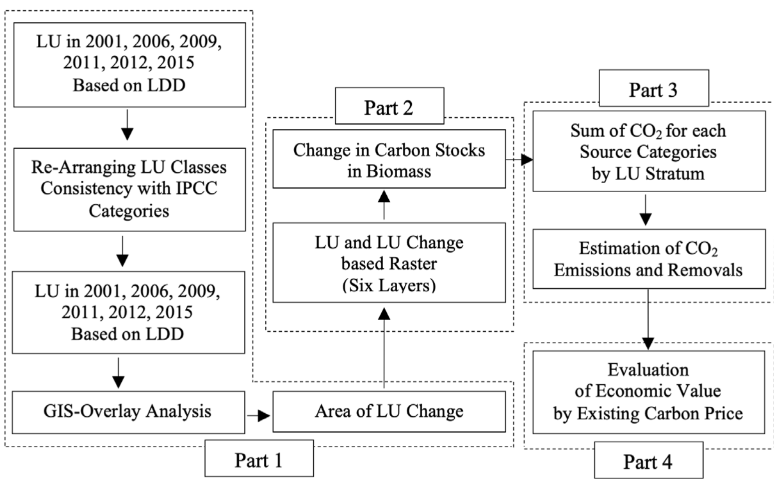

Figure 2. Research Methodology Framework

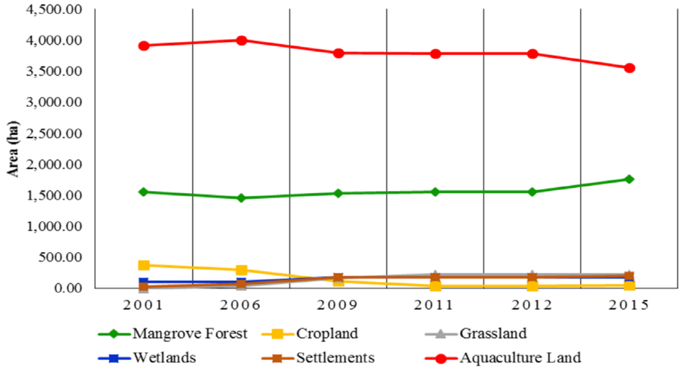

Figure 3. Trend of land use distribution (ha) in Yi San Sub-district, Samut Songkhram Province, Thailand during 2001-2015

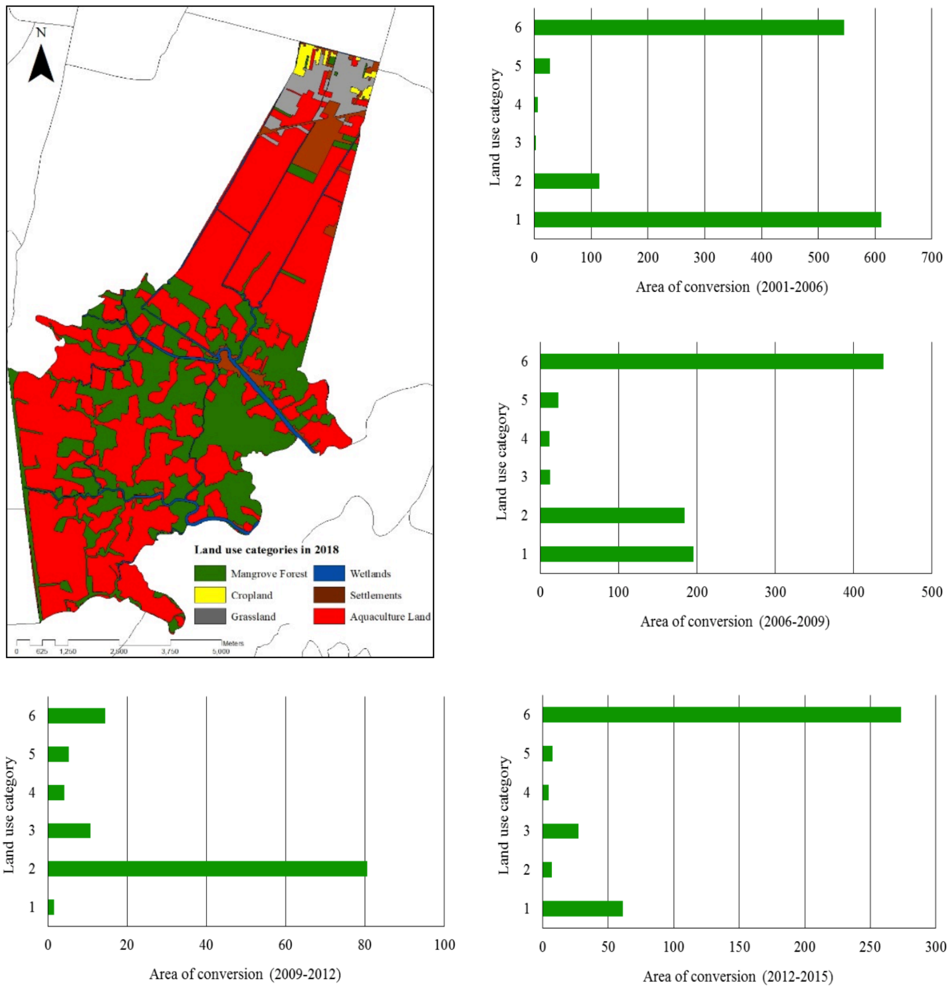

Figure 4. Land use category conversion in coastal area of Yi San Sub-district, Samut Songkhram Province, Thailand from 2001 to 2015 (unit: ha). The number 1 to 6 in each bar chart represent the area change of mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land respectively.

+123,043.83 tCO_2 and net total carbon dioxide removals were -190,409.73 tCO_2. The land use with the highest carbon dioxide emission was the aquaculture land (+81,696.64 tCO_2), followed by the grassland (+35,058.26 tCO_2) and settlements (+5,509.30 tCO_2), respectively. The land use with the highest amount of carbon dioxide removal was the mangrove forest (-186,012.28 tCO_2), followed by the cropland (-2,257.41 tCO_2) and grassland (-2,140.04 tCO_2), respectively (Table 3). During 2001-2006, the largest carbon dioxide emission source was aquaculture land (+58,413.61 tCO_2). In contrast, 2012-2015, the largest carbon dioxide removal by sink was mangrove forest (-41,812.22 tCO_2) (Supplementary Table 3). In Table 3, the result showed that mangrove forest plays an important role in mitigating global warming by CO_2 removal up to -190,409.73 tCO_2. If without mangrove area, the total CO_2 removal would drop to only -4,397.45 tCO_2 and the proportions of CO_2 emissions in Yi San Sub-district were larger than CO_2 removals as +118,646.38 tCO_2 causing GHG problem in the atmosphere as illustrated in Figure 6.

This study is consistent with other research that indicate the importance of deforestation and conversion of mangrove ecosystems that have been predicted to result in significant carbon emissions. The potential emissions from the conversion of mangroves to shrimp ponds are among the largest measured carbon dioxide emissions from land use in the tropic. (Kauffman *et al.*, 2014). The conversion, restoration and use

Table 2. Distribution of land use (ha) in Yi San Sub-district, Samut Songkhram Province, Thailand during 2001-2015

Land categories	Area (ha)					
	2001	2006	2009	2011	2012	2015
Mangrove Forest *(Rhizophora apiculata)*	**1,550.52**	**1,454.32**	**1,528.24**	**1,551.84**	**1,551.84**	**1,755.43**
Cropland	**375.34**	**294.27**	**112.66**	**34.25**	**34.25**	**44.81**
Paddy field	41.50	27.32	0.00	0.00	0.00	0.00
Coconut	189.51	251.50	42.94	29.56	29.56	40.05
Orchard	144.33	9.10	69.72	4.69	4.69	4.76
Perennial	0.00	6.35	0.00	0.00	0.00	0.00
Grassland	**0.00**	**37.37**	**169.58**	**224.48**	**224.48**	**217.00**
Grass	0.00	37.37	21.05	21.07	21.07	26.08
Scrub	0.00	0.00	148.58	203.41	203.41	190.92
Wetlands	**100.38**	**97.93**	**182.56**	**182.56**	**182.56**	**182.56**
Settlements	**22.67**	**75.24**	**174.41**	**178.95**	**178.95**	**202.98**
Aquaculture Land	**3,912.63**	**4,002.41**	**3,794.09**	**3,789.46**	**3,789.46**	**3,558.76**
Total	**5,961.54**	**5,961.54**	**5,961.54**	**5,961.54**	**5,961.54**	**5,961.54**

Table 3. Carbon dioxide absorption (tCO_2) caused by land use changes in Yi San Sub-district, Samut Songkhram Province, Thailand during 2001-2015

Land categories	Year 2001-2015		
	Total CO_2 emissions (+) (tCO_2)	Total CO_2 removals (-) (tCO_2)	Total CO_2 absorption (tCO_2)
Mangrove Forest	0.00	-186,012.28	-186,012.28
Cropland	+779.63	-2,257.41	-1,477.78
Grassland	+35,058.26	-2,140.04	+32,918.22
Wetlands	0.00	0.00	0.00
Settlements	+5,509.30	0.00	+5,509.30
Aquaculture Land	+81,696.64	0.00	+81,696.64
Total (including mangrove forest)	**+123,043.83**	**-190,409.73**	**-67,365.90**
Total (excluding mangrove forest)	**+123,043.83**	**-4,397.45**	**+118,646.38**

Notes: Symbol (+) = Emissions Symbol (-) = Removals

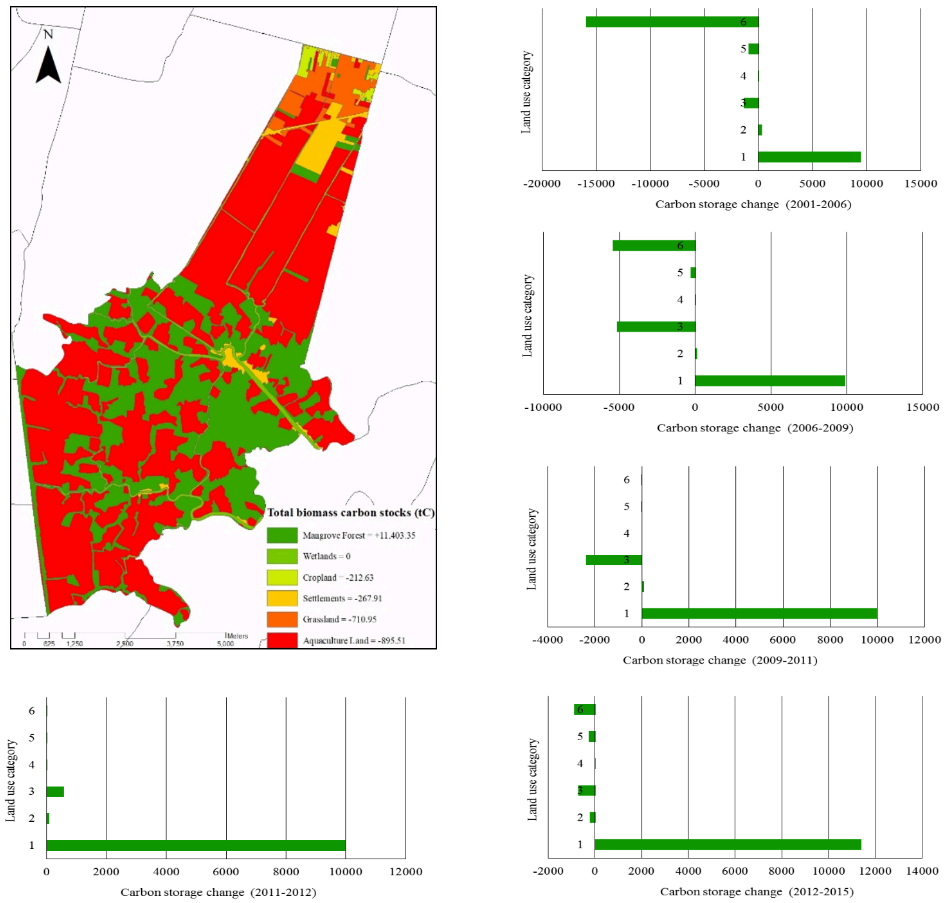

Figure 5. Carbon stock in biomass change caused by land use category conversion in coastal area of Yi San Sub-district, Samut Songkhram Province, Thailand between 2001 and 2015 (unit: tC). The number 1 to 6 in each bar chart represent respective different land cover change paths, namely, mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land.

Table 4. Carbon economic value (USD and THB) of CO_2 emissions and removals (tCO_2) in Yi San Sub-district, Samut Songkhram Province, Thailand during 2001-2015

Land categories	Carbon economic value by given price level		
	Total CO_2 absorption (tCO_2)	Carbon price	
		15.10 USD/tCO_2*	474.44 THB/tCO_2**
Mangrove Forest	-186,012.28	++2,808,785.43	++88,252,038.15
Cropland	-1,477.78	++22,314.48	++701,120.90
Grassland	+32,918.22	--497,065.12	--15,617,786.13
Wetlands	0.00	0.00	0.00
Settlements	+5,509.30	--83,190.43	--2,613,843.31
Aquaculture Land	+81,696.64	--1,233,619.26	--38,760,317.27
Total (including mangrove forest)	**-67,365.90**	++1,017,225.09	++31,961,212.33
Total (excluding mangrove forest)	**+118,646.38**	--1,791,560.34	--56,290,825.82

Notes: Symbol (+) = Emissions Symbol (-) = Removals
Symbol (++) = Gain of carbon economic value Symbol (--) = Loss of carbon economic value
* California Carbon Dashboard is voluntary market in March 29, 2018 (equal to 15.10 USD/tCO_2) (Thailand Greenhouse Gas Management Organization, 2018)
** Foreign exchange rate, 1 USD was equal to 31.42 THB (March 29, 2018) (Bank of Thailand, 2018)

of mangrove forest in eco-engineering solutions for coastal protection provide a promising strategy, delivering significant capacity for climate change mitigation and adaptation (Duarte *et al*., 2016).

3.3 Valuation of CO_2 emissions and removals in Yi San Sub-district, Samut Songkhram Province, Thailand for each period during 2001-2015

Valuation of CO_2 emissions and removals by the given carbon price from California Carbon Dashboard is voluntary carbon market, equal to 15.10 USD/tCO_2 (March 29, 2018) (Thailand Greenhouse Gas Management Organization, 2018). Results of the study showed that during 2001-2015 the gain of highest carbon value from CO_2 removals was the mangrove forests (2,808,785.43 USD), followed by cropland (22,314.48 USD). In contrast, the loss of highest carbon value

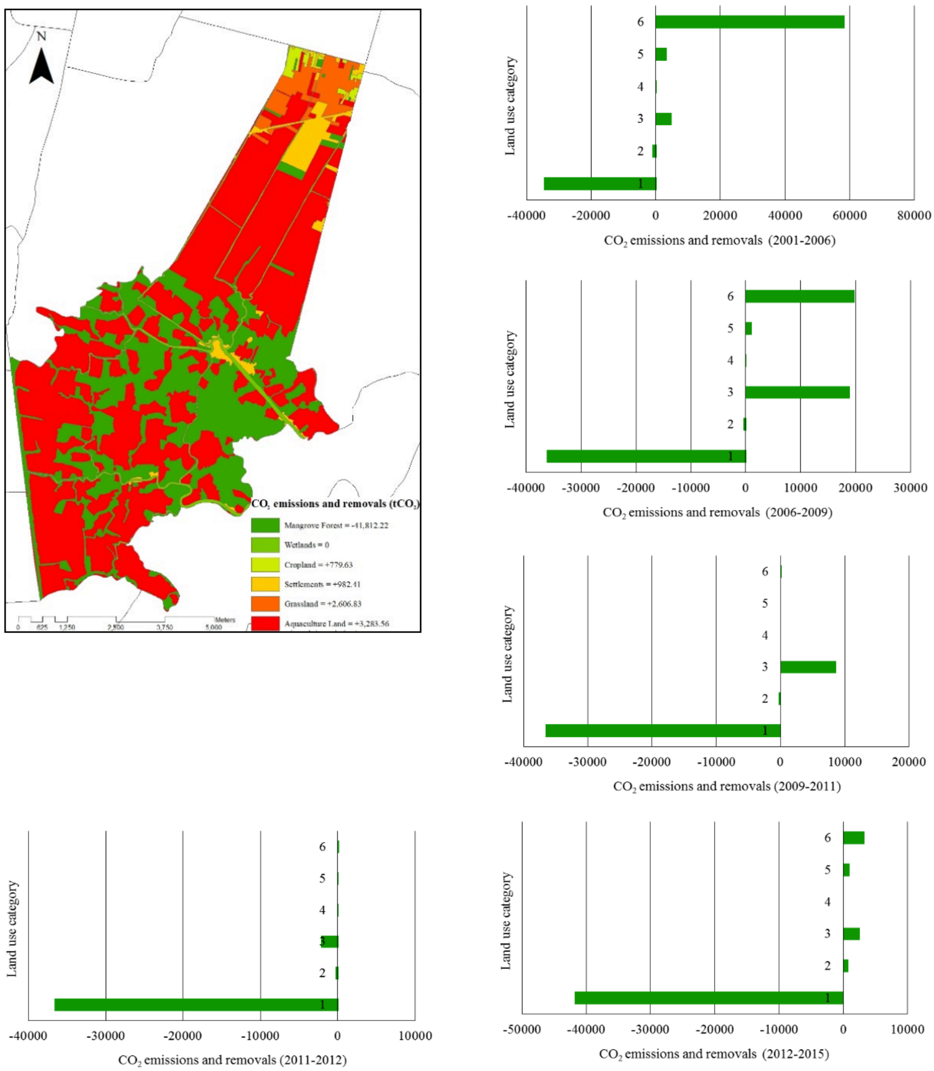

Figure 6. Carbon dioxide emissions and removals from remaining land use and category conversion in coastal area of Yi San Sub-district, Samut Songkhram Province, Thailand between 2001 and 2015 (unit: tCO_2). The number 1 to 6 in each bar chart represent respective different land cover change paths, namely, mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land.

from CO_2 emissions was aquaculture land (1,233,619.26 USD), followed by grassland (497,065.12 USD) and settlements (83,190.43 USD), respectively as illustrated in Table 4.

4. Conclusion

In this study, we present the changes in land use of Agriculture, Forestry and Other Land Use (AFOLU) sector using GIS application as a tool for accounting land use type area for each given periods, the amount of carbon stocks, and carbon dioxide emissions and removals from changes of 6 land use types (mangrove forest, cropland, grassland, wetlands, settlements, and aquaculture land) under the standard method of the 2006 IPCC, and valuation of carbon dioxide based on existing carbon price. The result showed that in Yi San Sub-district, Samut Songkhram Province, changes of land use influences terrestrial CO_2 sources and sinks. It could be summarized from the results that mangrove forests were identified as a CO_2 sink due to the highest increase in carbon stocks and the highest carbon economic gains. In contrast, aquaculture land was considered as a CO_2 emission source since most areas of mangrove forest, cropland, and grassland were converted to aquaculture. Thus, it caused decrease in carbon stock and losses of the highest economic value. GIS based spatial inventory and carbon economic value are beneficial to provide a database on greenhouse gas inventories status, trend of greenhouse gas emissions and reduction of greenhouse gas from land use changes for policy makers and optimization of land use in coastal area in the context of economic, social and environmental development at the level of Sub-district, coastal area or different levels in the future. However, the uses of the default emission and stock change factors for calculating CO_2 emissions and removals were not consistent with the actual carbon stock in the specific location. Thus, the practical emission factors should be made available by considering to the vegetation types, age of trees, and environment conditions. According to our findings, together with additional investigation on livelihood, social aspects, and other environmental aspects, knowledge generated can be beneficial to support environmentally sustainable communities along the coast.

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