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Spatial Inventory of CO_2 Emissions and Removals from Land Use and Land Use Changes in Thailand

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The main objective of this study aims to implement the spatial inventory of Carbon Dioxide (CO_2) emissions and removals during 2007-2012 resulting from carbon stock changes in biomass for all types of land. The methodological approach and land-use categories were based on the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines in the Agriculture, Forestry and Other Land Use (AFOLU) sector. To depict the spatial extend and distribution of CO_2 emissions and removals, Geographic Information System (GIS) was applied as a key tool for accounting the land-use changes and quantifying amount of CO_2 emissions per unit area. The results indicated that changes of above and below ground biomass during five years period lead to the net total CO_2 values of 15.32, 0.93, -0.59, and 0.02 $MtCO_2$ in Nan, Udonthani, Suratthani and Bangkok respectively. The proportions of CO_2 emissions in Nan were larger than CO_2 removals which were a result of conversions of forest land to crop land. In Udonthani, there are small amount of CO_2 emission due to the conversions of forest land to the various types of cropland. In Bangkok, there are the lowest CO_2 emissions during the study time period. This is because of the small proportions of above and below ground biomass. To accomplish the inventory in Bangkok, it needs to calculate an amount of CO_2 emission from other sectors. As a result of net CO_2 among emission and removal, it could be concluded that Suratthani was identified as a CO_2 sink. This is mainly due to the large coverage of forest land and perennial crop e.g. rubber and oil palm. In contrast, Nan was recognized as a CO_2 source with the large amount of CO_2 emission. The success of this study will lead to benefit for monitoring CO_2 status and for implementing more sustainable action, strategies, good practices and practical policy for CO_2 reductions at the local level for supporting the low carbon city.

1. Introduction

Global warming and climate change is recognized as the critical issue which recently influences to the physical environment, social and economic developments (Intergovernmental Panel on Climate Change: IPCC, 2007). In additions, climate change phenomenon affects to the variation of meteorological factors e.g. rainfall, wind velocity, and temperature (Xu et al., 2015).The Greenhouse Gas (GHG) concentrations in the atmosphere have been proportionally emitted from the human activities as shown in the changes of land-use patterns. Among GHGs, Carbon Dioxide (CO_2) with the lowest global warming potential contributes most to the current warming. The main sources of CO_2 are fossil fuel combustion, deforestation, and land-use changes related to above and below ground biomass, dead organic matter and soil carbon stock changes. Land use changes and land management influence a variety of ecosystem processes that affect greenhouse gas fluxes such as photosynthesis, respiration, decomposition, nitrification and combustion.The inventory of CO_2 emissions and removals can occur across all different types of land categories (IPCC, 2006). To implement the CO_2 spatial inventory, it needs to conclude the total change in areas of land categories which were sub-divided into land remaining in the same category and land converted from on category to another. In the developing countries, patterns of land-use have been dramatically changed relying on the seasonal, physical and socioeconomic conditions (IPCC, 2007).One of the most significant elements of CO_2 reduction leading to low carbon society is the reliable and precise of GHG emission and removal baseline. To determine such baseline, amount of CO_2 distributions in the spatial extent with the specific locations of source and sink have to be delineated.

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IPCC released the guidelines for national greenhouse gas inventories, e.g. revised 1996 and 2006 guidelines. There are six land-use categories in the 2006 IPCC guidelines including forest land, cropland, grassland, wetland, settlement, and other land. This guideline improved the estimate methodology and provided the three different approaches used to represent the areas of land-use categories depending on the details of data and acquisition (IPCC, 2006). An approach 1 identifies the total change in areas for each individual land-use category within a country, but does not provide information on the nature and area of conversions between land-uses. An approach 2 introduces the tracking of land-use conversions between six land categories, but is not spatially explicit. Approach 3 extends approach 2 by allowing land-use conversions between two time periods to be tracked on a spatially explicit basis. In general, only approach 3 will allow for the CO_2 spatial distributions and geo-reference of CO_2 sources and sinks.

To establish the CO_2 spatial inventory based approach 3, Geographic Information System (GIS) was needed to apply both for detecting the extents of land-use change and for quantifying the CO_2 emissions and removals per unit area. GIS based GHG inventory allow us to identify what an activity is (urbanization, deforestation, etc.), where the emissions source or sink are, and how much GHG emissions. GIS based tools have been also developed for accounting GHG emissions and reductions with the various purposes, for example, GHG from reforestation and deforestation (Richards and Brack, 2004), mapping individual anthropogenic CO_2 point sources in fossil-fired power plants geo-referencing carbon sources and sinks based land-use change (Ponce-Hernandez, 2004).

In Thailand, Initial National Communication (INC) and the Second National Communication (SNC) which represents the national greenhouse gas inventory were submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2000 and in March 2011, respectively (ONEP, 2010). Annual GHGs Inventory reports in Land sector were implemented using the statistical data based approach 1based the national data level. Thus, the inventory results cannot support the facilitation of low-carbon policy making at the local or municipal level. To mitigate greenhouse effects, it is essential to issue the policy and produce an action plan particularly in regional, local and city scale based temporal-spatial data (Asdrubaliet al., 2013).The main objective of this study aims to implement the spatial inventory of CO_2 emissions and removals during 2007-2012 resulting from carbon stock changes in biomass for all types of land. The methodological approach and land-use categories were based on the 2006 IPCC guidelines in the Agriculture, Forestry and Other Land Use (AFOLU) sector. GIS based spatial inventory is beneficial for monitoring CO_2 status, and implementing more sustainable action, strategies, good practices and practical policy for CO_2 reductions at the local level for supporting the low carbon city.

2. Study Area

In this study, the four provinces with the different dominance in land-use types were selected for evaluating the proposed GIS-based CO_2 inventory. Nan province with the complicated mountain and the large proportion of forest land and cropland is located at the north of Thailand (centered at 18^o 51’ 3.96” N 100^o 50’ 6.36” E). Udonthani province is situated at the north eastern region and most areas are covered with an annual crop plantation such as rice, corn and cassava (centered at 17^o 25’ 30.54” N 102^o 51’ 47.52” E). Suratthani province located in the south region has the large spatial extents of perennial tree crops e.g. oil palm, rubber (centered at 9^o 3’ 3.79” N 99^o 5’ 21.4” E). At last in Bangkok, all of areas are mainly utilized for settlement, business and industry (centered at 13^o 46’ 17.22” N 100^o 37’ 19.92” E).

3. Research Methodology

A GIS-based technical framework and five crucial steps of accounting and mapping the CO_2 emissions and removals were illustrated in Figure 1. The details of each step were summarized as below.

3.1 Re-arranging land use categories

The spatial layers (1: 25,000) of land-use categories which were interpreted from satellite image, aerial photo and ground survey operated by the Land Development Department (LDD) were used as the activity data source. However, five main land-use categories 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 based the 2006 IPCC guidelines were sub-divided into land remaining in the same category and land converted from on category to another. Each land category was further subdivided into sub-categories For instance, classes of cropland categories consist of the long-term cultivated, paddy rice and perennial tree crop.

3.2 Classifications of land-use change

The CO_2 inventory based 2006 IPCC guidelines focused both on the remaining and conversion of land-use category. Before measuring the CO_2 emissions and removals, types of land-use change were derived by the overlay of re-arranging land use layers based IPCC category in 2007 and 2012. The comparisons of six land-use categories in 2007 and 2012 resulted in the 34 different types. Subsequently, 34 IPCC default codes were determined into the vector attributes to classify the types of land-use change.

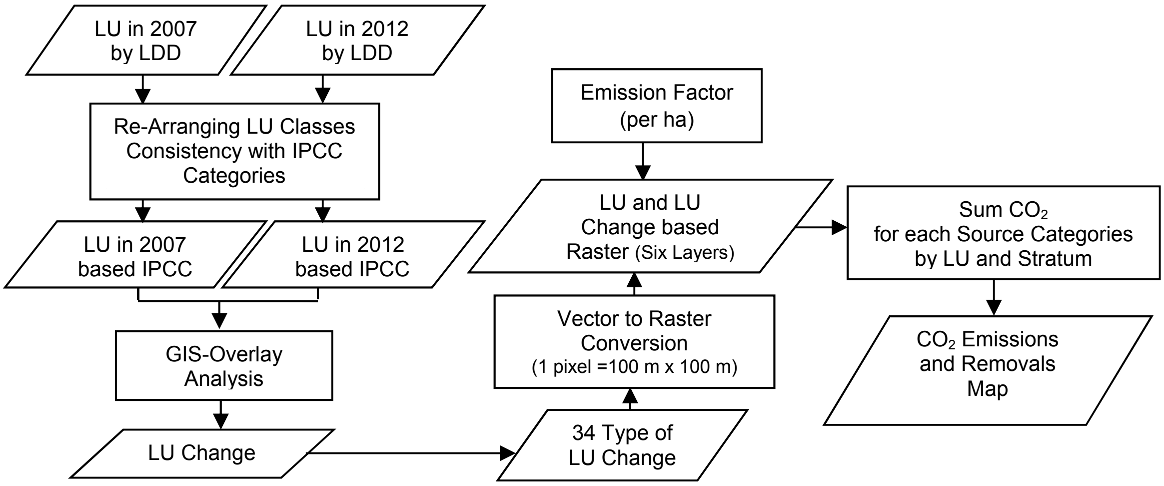

Figure 1: Research Methodology Framework

3.3 Conversions of land-use changes based vector to raster format

To make the possibility to detect the total areas of land conversion type, polygon features of land-use change were converted to the raster format which represents the data with the equally square grid. The pixel size of each grid was 100 x 100 in meter which corresponds to the minimum unit area of IPCC emission factor (tonnes C per ha).

3.4 Calculation of CO_2 emissions and removals

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 (IPCC, 2006).For all subdivisions of land area category, carbon stock changes were separately calculated and summarized in six land-use categories as shown in Eq(1).

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

where ΔC_{AFOLU} is carbon stock change in AFOLU sector, FL is Forest Land, CL is Cropland, GL is Grassland, WL is Wetlands, SL is Settlements and OL is Other Land

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 Eq(2). Gains can be attributed to biomass growth at above and belowground components. Losses are categorized into wood harvesting, and losses from natural disturbances such as fire and flooding.

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

where ΔC_B is annual change in carbon stocks in biomass for each land sub-category (tonnes C yr^{-1}). ΔC_G is annual increase in carbon stocks due to biomass growth for each land sub-category. ΔC_L is annual decrease in carbon stocks due to biomass loss for each land sub-category.

The inventory of CO_2 emissions and removals in the four provinces with the different of dominant land use types were conducted over the inventory period. In this study, the parameter values such as emission and stock change factors that are based on the country-specific data were used to calculate the carbon change in the forest land. However, the country specific emission factors in other land-use categories were not yet readiness. Thus, the tier 1 default emission factors which were provided by the 2006 IPCC guidelines were utilized. The default values were appropriately determined by considering both an ecological zone and climate domain of

Thailand. Subsequently, each grid cell was possible to assign a specific value of CO_2 which were corresponding to the types of land-use changes, emission and stock change factors**.** The CO_2 emissions or removals have been represented using a mesh of 1 ha square cells.

4. Results and Discussion

4.1 Magnitudes of the land use remaining and land conversions

The main proportions of land-use categories in Nan province were the forest land and cropland with 64.74 % and 32.49 %, respectively. As a result of land-use change detections, it can be noticed that Nan province loss the forest lands approximately 74,400 ha during five years of investigation. The forest lands were converted to other land use types, particularly to croplands with the total areas of 89,741 ha. However, there is the increasing of forest lands with the total areas of 15,962 ha. In Udonthani province, most of areas in 2012 were utilized for cropland and forest land with the total area of 697,565 ha (67.68 %) and 193,559 ha (18.78 %), respectively. In additions, the total forest areas of 12,332 ha (1.12 %) were changes to cropland e.g. rubber, sugarcane. In Suratthani province, there is the largest coverage of perennial crop parcel in the southern region of Thailand. Most of croplands cultivated the rubber, orchard and oil palm with the total area of 789,985 ha (60.4%) in 2012. It can observe that Suratthani loss the forest lands with the total areas of 13,895 ha during five years. In Bangkok, there are the total croplands and settlements of 28,518 ha (18.21 %) and 100,432 ha (64.14%) in 2012, respectively. It can be concluded that there are the extents of settlement with approximately 4,021 ha during five years as illustrated in Table 1.

Table 1: The sample of Land- use Change Matrix in Suratthani province

Province	Land categories	Land-Use Change Matrix (ha)						
		FL	CL	GL	WL	SL	OL	Final area (2012)
Suratthani	FL	398,053	196	44	1	-	3	398,297
	CL	13,942	759,859	9,084	2,016	4,560	524	789,985
	GL	131	771	17,441	4	78	43	18,468
	WL	-	-	-	45,470	-	-	45,470
	SL	23	906	299	44	33,317	6	34,595
	OL	43	245	39	14	75	20,681	21,097
Initial area (2007)		412,192	761,977	26,907	47,549	38,030	21,257	1,307,912

4.2 The spatial distributions of GHGs concentration

With the multiplication between the total areas of land remaining or land conversion and emission factor (tonnes C per ha), it is possible to map the spatial distributions of CO_2 emissions and removals within a mesh of 1 ha square cells. The total emission causes the carbon stock loss in biomass which corresponds to the land-use categories including forest land, cropland, grassland, settlement, wetland and other lands. The results indicated that changes of above and below ground biomass during five years period lead to the net total CO_2 values of 15.32, 0.93, -5.94, and 0.02 $MtCO_2$ in Nan, Udonthani, Suratthani and Bangkok respectively. The details of CO_2 emissions and removals were illustrated in Table 2.

The loss of forest land during five years period of 89,741 ha in Nan province was mainly through the conversions to crop land which resulted in the large proportions of CO_2 emission with values of 17.52 $MtCO_2$. However, the remaining of forest lands and croplands during five years can uptake the CO_2 values of 1.88 and 0.54 $MtCO_2$. Thus, it could be conclude that Nan is the largest CO_2 source among the four study areas. This is mainly due to the loss of forestlands resulting in the loss of carbon stock. When considered the subdivided land-use classes within the changed areas, it found that most of forest land was changed to maize and rubber plantations.

In Udonthani, the total CO_2 emissions mainly cause the forest land converted to cropland with the total area of 12,332 ha resulting in emissions of 1.63 $MtCO_2$. However, the remaining of forest lands and croplands during five years can absorb the CO_2 values of 0.92 and 0.85 $MtCO_2$ respectively via the photosynthesis process. Most of the cultivated croplands were an annual trees e.g. sugarcane, oil palm and cassava. With the net total CO_2 value of 0.93, it could be said that Udonthani is the rather small CO_2 source.

Suratthani is considered as the CO_2 sink. This is mainly because of the large coverage of forest lands and perennial crop e.g. rubber, orchard and oil palm. The remaining of forest lands and croplands during five years can remove the CO_2 from the atmosphere with the values of 2.39 and 7.12 $MtCO_2$ respectively.

Table 2: CO_2 emissions and removals from Land Use and Land Use change during 2007- 2012

Land Categories	CO_2 Emissions and Removals (tCO_2)			
	Nan	Udonthani	Suratthani	Bangkok
Total	15,324,674	937,355	-5,943,558	21,475
3.B.1 - Forest land	-2,027,118	-1,181,318	-2,388,746	-957
3.B.1.a - Forest land Remaining Forest land	-1,882,660	-924,529	-2,387,120	-832
3.B.1.b - Land Converted to Forest land	-144,458	-256,789	-1,626	-125
3.B.1.b.i - Cropland converted to Forest Land	-134,700	-230,118	-1,354	-82
3.B.1.b.ii - Grassland converted to Forest Land	-8,784	-21,648	-259	-20
3.B.1.b.iii - Wetlands converted to Forest Land	-41	-862	-3	-
3.B.1.b.iv - Settlements converted to Forest Land	-931	-1,384	-	-10
3.B.1.b.v - Other Land converted to Forest Land	-2	-2,777	-10	-13
3.B.2 - Cropland	17,026,942	951,370	-3,753,462	-17,271
3.B.2.a - Cropland Remaining Cropland	-537,530		-7,120,040	-16,668
3.B.2.b - Land Converted to Cropland	17,564,472	1,796,843	3,366,578	-603
3.B.2.b.i - Forest Land converted to Cropland	17,515,000	1,627,661	3,151,370	-
3.B.2.b.ii - Grassland converted to Cropland	52,350	188,442	282,872	4,229
3.B.2.b.iii - Wetlands converted to Cropland	-219	-11,045	-19,213	-391
3.B.2.b.iv - Settlements converted to Cropland	-2,659	-1,839	-43,457	-3,469
3.B.2.b.v - Other Land converted to Cropland	-	-6,376	-4,994	-972
3.B.3 - Grassland	233,651	827,554	156,887	5,354
3.B.3.a - Grassland Remaining Grassland	-	-	-	-
3.B.3.b - Land Converted to Grassland	233,651	827,554	156,887	5,354
3.B.3.b.i - Forest Land converted to Grassland	56,260	179,711	35,718	1092
3.B.3.b.ii - Cropland converted to Grassland	179,016	677,156	127,471	20,400
3.B.3.b.iii - Wetlands converted to Grassland	-90	-21,029	-212	-559
3.B.3.b.iv - Settlements converted to Grassland	-1,535	-4,886	-3,940	-14,728
3.B.3.b.v - Other Land converted to Grassland	-	-3,398	-2,150	-851
3.B.5 - Settlements	68,356	135,714	33,757	30,538
3.B.5.b - Land Converted to Settlements	68,356	135,714	33,757	30,538
3.B.5.b.i - Forest Land converted to Settlements	55,205	91,716	4,990	-
3.B.5.b.ii - Cropland converted to Settlements	9,770	23,792	16,607	13,528
3.B.5.b.iii - Grassland converted to Settlements	3,381	20,206	12,160	17,010
3.B.6 - Other Land	22,843	204,035	8,006	3,811
3.B.6.b - Land Converted to Other land	22,843	204,035	8,006	3,811
3.B.6.b.i - Forest Land converted to Other Land	18,570	150,757	1,901	-
3.B.6.b.ii - Cropland converted to Other Land	1,338	29,255	4,491	2,090
3.B.6.b.iii - Grassland converted to Other Land	-	24,023	1,614	1,721
3.B.6.b.iv - Wetlands converted to Other Land	2,935	-	-	-

The conversions of forestland to crop lands in Udonthani with the total areas of 12,332 ha resulted in the emission values of 1.62 $MtCO_2$. While the total areas of forestland conversion in Suratthani are a similar amount to Udonthani with the total areas of 13,942 ha, but releasing the larger proportion of emission values of 3.15 $MtCO_2$.This is mainly due to the forest type in Suratthani is the tropical rain forest which stocks the large biomass before the conversion (280 t dm ha^{-1}) comparing to the small one in the dry forest (130 t dm ha^{-1}) which usually found in Udonthani.

Bangkok emitted the lowest CO_2 among the four study areas because all of areas were used for settlement, business and industry which a small biomass stocks. It lead to released CO_2 emission due to biomass change with value of 0.03 $MtCO_2$. However, it could not summarize that Bangkok is the smallest CO_2 source. To accomplish the CO_2 inventory in Bangkok, it also needs to calculate an amount of emission from energy, industry, and transportation sector.

With the proposed method, concentrations and distributions of CO_2 sources and sinks were possibly to boundary and locate. Maps of spatial CO_2 emission and removal in the four provinces were illustrated in Figure 2.

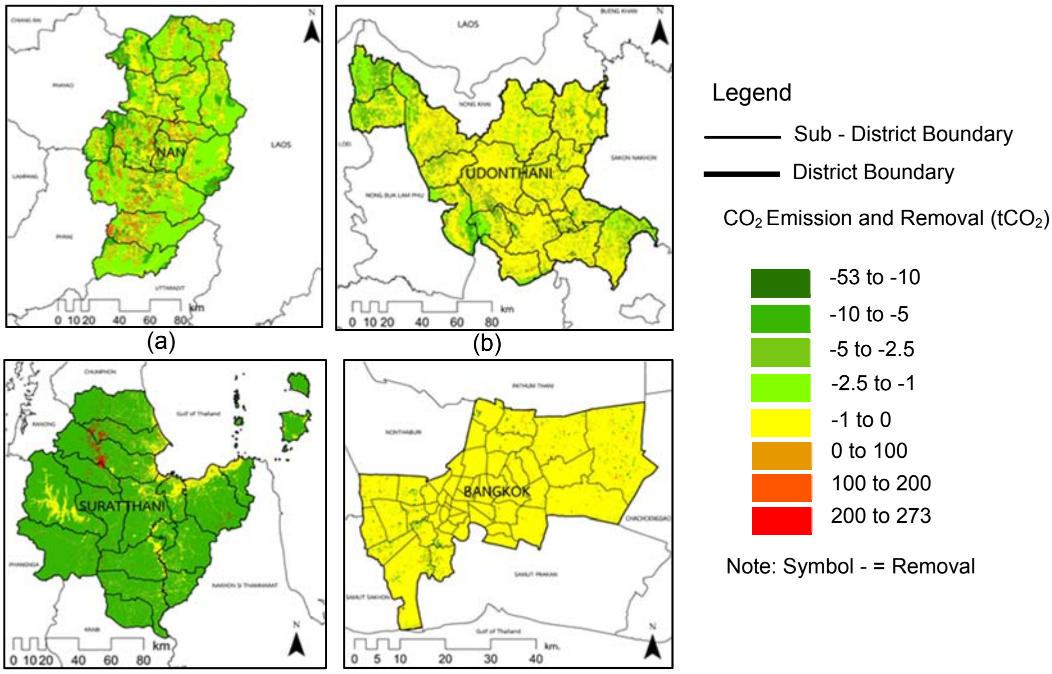

Figure 2: Spatial CO_2 emission and removal from Land Use and Land Use Change in (a) Nan (b) Udonthani (c) Suratthani and (d) Bangkok

5. Conclusions

In this work, Geographic Information System (GIS) was applied as a key tool for implementing the spatial inventory of Carbon Dioxide (CO_2) emissions and removals during 2007 - 2012 resulting from the carbon stock changes in biomass for all types of land. The calculations of CO_2 were based on the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines in the Agriculture, Forestry and Other Land Use (AFOLU) sector. With the performances of GIS, it allows us to map the CO_2 spatial distributions and geo-reference of CO_2 sources and sinks. It could be summarize from the results that Nan, Udonthani and Bangkok was identified as a CO_2 emission source. In contrast, Suratthani was considered as a CO_2 sink due to the large coverage of the forest land and perennial tree crop. GIS based spatial inventory is beneficial for monitoring CO_2 status, and implementing more sustainable action, strategies, good practices and practical uses to be baseline emission for supporting the implementation of greenhouse gas reduction at the level of district, sub-district or boundary of municipality. However, the uses of the default emission and stock change factors for calculating CO_2 emissions and removals which were not consistent with the actual carbon stock in the specific location. Thus, the practical emission factors should be available by considering to the vegetation types and environment conditions.

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