Carbon dioxide emissions from forestry and peat land using land-use/land-cover changes in North Sumatra, Indonesia

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Abstract. Forestry and peat land including land-based is one of the critical sectors in the inventory of CO\(_2\) emissions and mitigation efforts of climate change. The present study analyzed the land-use and land-cover changes between 2006 and 2012 in North Sumatra, Indonesia with emphasis to CO\(_2\) emissions. The land-use/land-cover consists of twenty-one classes. Redd Abacus software version 1.1.7 was used to measure carbon emission source as well as the predicted carbon dioxide emissions from 2006-2024. Results showed that historical emission (2006-2012) in this province, significant increases in the intensive land use namely dry land agriculture (109.65%), paddy field (16.23%) and estate plantation (15.11%). On the other hand, land-cover for forest decreased significantly: secondary dry land forest (7.60%), secondary mangrove forest (9.03%), secondary swamp forest (33.98%), and the largest one in the mixed dry land agriculture (79.96%). The results indicated that North Sumatra province is still a CO\(_2\) emitter, and the most important driver of emissions mostly derived from agricultural lands that contributed carbon dioxide emissions by 48.8%, changing from forest areas into degraded lands (classified as barren land and shrub) shared 30.6% and estate plantation of 22.4%. Mitigation actions to reduce carbon emissions was proposed such as strengthening the forest land, rehabilitation of degraded area, development and plantation forest, forest protection and forest fire control, and reforestation and conservation activity. These mitigation actions have been simulated to reduce 15% for forestry and 18% for peat land, respectively. This data is likely to contribute to the low emission development in North Sumatra.

1. Introduction
Forestry and peat land in the context of climate change including the LULUCF (land-use, land-use-change, and forestry) sector is one of the significant areas in the inventory of greenhouse gas (GHG) emissions. The substantial contribution of the forestry sector in GHG emissions derived from deforestation and forest degradation [1-2]. Deforestation as defined by the conversion of forests to non-forest land-use, while degradation shows that forests remain forests but lose their ability to support ecosystem services or deteriorate main changes in species composition due to overexploitation, pollution, fires, or other factors [3]. Apart from degradation, the contribution of GHG emission was also generated from peat fires and cultivated peat land [4]. Several factors triggering the deforestation and degradation in Indonesia, including in North Sumatra are illegal logging; forest fires, and conversion of forest to other land-use that produced land-cover with lower carbon stocks such as estate plantations and agriculture, regional expansion, mining and settlement [1-2,4].
The Government of Indonesia has made voluntarily committed to a minimum 26% reduction in GHG emissions by 2020 and up to 41% with international assistance such as finance or other support, developed a strategy for land-use, and extended a moratorium on new clearing of primary forests and peat lands [6]. Recently the commitment has been revised that Indonesian government has pledged to reduce the GHG emissions 29% by 2030 through speeding up protection of forests and boosting the renewable energy sector [7].

By wide geography range in Indonesia, the potential reduced emissions from the land-based sector are implemented in provincial and regency levels through Regional Action Plan for Greenhouse Gas Emissions Reduction. In spite of the importance of forests to play a significant role in the carbon cycle and climate change, no information on the carbon emission from a land-based change in North Sumatra province has previously been available. Thus, this study aimed to analyze the land-use and land-cover changes between 2006 and 2012 in North Sumatra province, Indonesia with particular reference to CO2-eq emissions.

2. Materials and Method

2.1. Study area

The study was carried out in North Sumatran forest, Indonesia (Figure 1), which located between at 01° - 04° North latitudes and between at 98° - 100° East longitudes. North Sumatra province bordered by Aceh province in the North, the Indian Ocean in the West, Riau and West Sumatra in the South, and Malacca Strait is in the East. North Sumatra has a total area of 181,860.65 km², consisting of the land area of 71,680.68 square kilometers. There are 25 regencies and eight cities in North Sumatra province to be included in this study.

2.2. Analysis of land-use and land-cover changes

Land use and land-cover data between 2006 and 2012 of North Sumatra province were obtained from Ministry of Forestry, Indonesian Government and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite image were acquired from USGS (http://glovis.usgs.gov/). The Regional Land Use Plan map of North Sumatra Province provided the spatial planning zone of this province year 2012 was derived from Development Planning Agency of North Sumatra Province.

![Figure 1. Location of study area showing forest region and non-forest region in North Sumatra](image-url)
Analysis of the Landsat images was conducted by employing supervised categorization as previously reported [8]. Image pre-processing, the process of image analysis, appearance arrangement and change detections were done by ERDAS Imagine 8.7 (ERDAS, Atlanta). Post interpretation with the ground check was conducted by Global Positioning System (GPS) to collect information of current land-use/land-cover. Geographic Information System (GIS) analysis was performed by ArcGIS 9.3.1 and ArcView 3.3 (ESRI, USA). Land use and land-cover categorizations in this study were from the Ministry of Forestry, Indonesian Government published in 2000.

2.3. GHG measurements and mitigation scenario

The REDD Abacus SP software version 1.1.7 [9] developed by the World Agroforestry Center was used to measure the GHG emissions source as well as the predicted CO2 emissions over 2006-2024 from land use/land-cover of North Sumatra province. The mitigation scenarios to reduce GHG emissions based on historical emission baseline using REDD Abacus as previously described [9] and several activities proposed.

3. Results and Discussion

The results discussed in three subsections, namely land-use/land-cover changes between 2006 and 2012, carbon dioxide emissions from land-use, and developing a scenario to reduce GHG emissions.

3.1. Land-use/land-cover changes between 2006 and 2012

Figure 2 depicts the land use/land-cover changes in North Sumatra over 2006-2012. The land use/land cover in North Sumatra consists of 21 classes. There are seven forest areas, namely primary dry land forest, secondary dry land forest, primary swamp forest, secondary swamp forest, primary mangrove forest, secondary mangrove forest, plantation forest. Four croplands: estate, dry land agriculture, mixed dry land farming, and paddy field. Furthermore, other land-uses such as shrub, swamp shrub, aquaculture, settlement, transmigration, barren land, water body, swamp, and cloudy.

![Land-use/land-cover changes](image)

**Figure 2.** Land-use/land-cover change in North Sumatra in period 2006-2012

Figure 2 shows that the land-use decreases significantly in the land-cover of forests, i.e. secondary dry land forest (7.60%), secondary swamp forest (33.98%) and secondary mangrove forest (9.03%) and mixed dry land agriculture (79.96%). Meanwhile, there were also significant increases in the...
intensive land-use such as plantation (15.11%), dry land farming (109.65%) and paddy field (16.23%). The estate farm, dry land agriculture, and paddy field are responsible for deforestation in this study. It has been reported that deforestation reduced forest canopy cover below 10-30% [2].

3.2. Carbon dioxide emissions from land-use
Based on Table 1, land-cover change in 2006 to the land-cover in 2012 occurred in the forest and non-forest area. Mixed dry land agricultural land-uses contributed emissions by 47.9%, followed by estate plantation (22.0%), and replacement of forest to degraded land (barren land and shrub) shared 30% of carbon emissions (Table 1). This finding suggested the interesting note that the change of secondary dry land forest, secondary swamp forest, plantation forest as a source of emissions contributing to the barren land.

The historical emissions (2006-2012), the North Sumatra is dominated by the agricultural zone (4.08 million t CO$_2$-eq) or contributed to approximately 37%, then the annual crop region (of 1.38 million t CO$_2$-eq). For the forested area, the largest historical emissions are shown by the Protected Forests (1.09 million t CO$_2$-eq), followed by production forest (962 thousand t CO$_2$-eq) and limited production forest (877 t CO$_2$-eq) (data not shown).

| Table 1. Carbon emission source from land-use and land-cover change |
|---------------------------------------------------------------|
| Land-use (2006) | Land-use (2012) | Share (%) |
| Mixed dry land agriculture | Dry land agriculture | 47.9 |
| Estate Plantation | Estate Plantation | 22.0 |
| Plantation forest | Barren land | 9.1 |
| Secondary dry land forest | Barren land | 7.1 |
| Secondary swamp forest | Barren land | 4.7 |
| Mixed dry land agriculture | Shrub | 4.7 |
| Secondary dry land forest | Shrub | 4.4 |
| Total | | 100 |

| Table 2. BAU based on historical data and reduction scenario for forestry and peat land |
|----------------------------------------|
| Sector | 2006-2012 (t CO$_2$-eq/year) | 2012-2018 (t CO$_2$-eq/year) | 2018-2014 (t CO$_2$-eq/year) | Decrease (%) |
| BAU of forestry | 58,754,351 | 79,796,961 | 92,973,433 |
| Mitigation of forestry | 58,754,351 | 73,413,204 | 79,027,418 | 15.2 |
| BAU of peat | 26,023,614 | 59,335,316 | 94,897,665 |
| Mitigation of peat | 26,023,614 | 51,028,371 | 77,816,085 | 18.0 |

The BAU (business as usual) GHG emission baseline for the Forestry sub-sector of North Sumatra Province is prepared by projecting the land uses and land-cover changes in the future using historical data without any intervention to climate change mitigation policy/technology as well as the spatial pattern information. Table 2 shows the historical emission (2006-2012) of forestry and peat land were 58,754,351 and 26,023,614 (t CO$_2$-eq/year), respectively. Table 2 demonstrates that the emission Reference Level (RL) is calculated based on the historical data. Cumulatively, the net emission for the Forestry sub-sector of North Sumatra Province in 2012-2018 about 79.79 million t CO$_2$-eq/year, with the prediction emission in 2018-2024 is 92,973,433 t CO$_2$-eq/year. Table 2 shows cumulative the net issuance for the Peat Land sub-sector of North Sumatra Province in 2012 is 59.33 million t CO$_2$eq /year.
It has been shown that net emission from intensive agriculture and estate plantations attributed to deforestation, the deforestation accounts as majority emissions and forest degradation is less contribution [1]. The degradations in North Sumatra are wood cuttings, forest fires, cultivated peat land, and pollution [4-5,8].

3.3. Developing scenario to reduce GHG emissions

The mitigation scenarios will serve as an outstanding effort involving the activities leading to reduce GHG emission in North Sumatra Province taking into account the dynamic changes in land-use and land-cover as well as the condition of forest tree cover. During the preparation of land-based mitigation scenario for GHG emitted by the forestry and peat land sector in North Sumatra Province, a reduced GHG emission value based on historical baseline data was predicted as depicted in Figure 3 and Table 2.

The reduced emission scenario actions in Table 2 and Figure 3 will be potential to a lower the total cumulative % of GHG emission equivalent to 79.03 million and 77.16 million tons CO2-eq/year from forestry and peat land, respectively by 2020 in the province of North Sumatra. On the other hand, the mitigation action for the forestry and peat land sector in the area indicates the core, as well as supporting activities, was simulated. Six mitigation activities were proposed to reduce GHG 15% in forestry and 18% in peat land, namely, firstly strengthening the forest areas. The scenario activities include the preservation of dry land primary forest, peat swamps, mangrove forests and dry land secondary forests, peat swamps and mangrove forests while preventing the conversion of primary and secondary forests to other uses. These activities are proposed to reduce 1.97 million CO2-eq/year or equivalent to a contribution of 1.68% emission reduction. The secondly, the rehabilitation of degraded mangroves, which is expected to reduce carbon emission by 411 thousand CO2-eq/year with mitigation action includes the procurement of mangrove-type seed and seedlings, seeding and nursery activities of mangrove types, rehabilitation mangrove forest and other degraded land and building mangrove forest community groups [6].

![Figure 3. BAU baseline based on scenario to reduce emission in forestry and peat land sectors](image_url)

The third scenario by forest development and planted a forest. This action is planned to reduce 15.46 million CO2-eq/year, with mitigation action is the program and activity planning and availability of data/information on forest development activity in North Sumatra Province (cross district/city); indigenous forest, village forest, and planted forest development and preservation. The fourth effort by forest protection and forest fire control will be reduced 8.75 million GHG emissions. The activities include structuring the forest boundaries, reducing cases of illegal logging, forest encroachment, forest fires, and destruction, addressing the violations of forest product distribution, an awareness campaign.
to the surrounding community on the forest fire prevention and control. Other actions were to strengthen agreement/cooperation of all stakeholders (community, government and business) for the forest protection and security, assistance to the surrounding community through outreach activity and Preservation of indigenous forest, village forest and social forest and conservation of the woods plant types.

The fifth scenario to utilize the agriculture land, for the provision of information on agriculture area for the use of perennial crops, use of farm land for indigenous forest planting, provision of data on have a loan of and use permits of agriculture area. This action plan will reduce emission by 364 thousand CO$_2$-eq/year. The last scenario by reforestation and conservation activity was expected to reduce 4.06 million CO$_2$-eq/years. The reduction scenarios include the provision of forest plant types and multi purpose tree species and their establishment for activity implementation, rehabilitation of open area, bushes in creating a secondary forest, conservation of plantations resulted from restoration activity, reforestation activities in the forests and greening activities outside the areas [1].

4. Conclusions
North Sumatra Province was still a CO$_2$-eq emitter, and the largest driver of emissions mostly derived from agricultural lands contributed CO$_2$-eq emissions by 47.99%, changing from forest areas into degraded lands (classified as barren land and shrub) shared 30.1% and estate plantation amounted 22%. The proposed scenario mitigation will reduce GHG 15% in forestry and 18% in peat land. This data is likely to contribute to the low emission development in North Sumatra.

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