Contribution of forest degradation in Indonesia’s GHG emissions: Profile and opportunity to improve its estimation accuracy

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Abstract. The degradation of tropical forests in Indonesia is perceived to be an essential contributor to land-based greenhouse gas (GHG) emissions, in addition to deforestation. However, the impacts of forest degradation are currently understudied and poorly understood, in comparison to deforestation, which is easier to be detected and thus more ready to be quantified and monitored. In order to understand better the contributing factors of Indonesia’s GHG emissions profiles from the forestry sector as well as taking the opportunity to tackle climate change, improving knowledge on GHG emissions from forest degradation is essential. Both literature review and simulation using a carbon accounting model were used in the analysis. National emissions profile of Indonesia has been reported to the UNFCCC, in which forest degradation has been one of the sources of emissions, although its emission value tended to be underestimated and may contain high uncertainty. It is because logging and fires in secondary forests have not been fully captured as sources of emissions, as well as post-disturbance growth that potentially enhance forest carbon stocks. This study clearly shows the importance of calculating GHG emissions from forest degradation caused by anthropogenic activities (logging, fires). It is suggested that accuracy can be improved by using a system approach that occurs in the ecosystem carbon cycle through modeling that can capture the flow of carbon following the disturbance events.

Keywords: Accuracy, disturbance, forest degradation, GHG emission, model

1. Introduction
The greenhouse gas (GHG) emissions released into the atmosphere from the Indonesia forestry sector are reported to be very high. During the period of 2000-2016, the average GHG emissions from the forestry sector reached 0.71 Gt CO\textsubscript{2}e [1]. Addressing these GHG emissions is essential and has become one of the environmental issues in both political and scientific agenda at the national and international levels. There are many reasons to argue that tropical forests are the most important forest ecosystems. They have accumulated gross primary productivity of 40 billion tonnes C per year [2], which serve as the most important terrestrial carbon sink [3] to reduce GHG emissions. Related to this critical role,
there has been an increased concern as well as collaborative actions at the national and international levels on the issue of climate change due to forest loss [4].

The land-based sector is the most significant contributors to the total GHG emissions, which is mostly caused by human activities through logging and fires impacting on deforestation and forest degradation events. The GHG emissions resulted from deforestation have been widely discussed at the national, regional, and international levels, in terms of measurement and monitoring as well as efforts that need to be taken in the mitigation actions. On the other hand, forest degradation has not been widely studied comprehensively, although its contribution is significant to the level of GHG emissions in Indonesia. The study [5] showed the importance of forest degradation as a significant source of GHG emissions.

Destruction of primary forests or natural forests has led to the expansion of secondary forest areas, triggering the increased interest in understanding more deeply on the role, structure, and function of secondary forests [6]. The existence of secondary forests as a result of disturbance by logging or fires is one of the essential components for climate change mitigation in Indonesia. The area of secondary forests has also increased globally over time, not only in Indonesia but also in several other tropical countries. The large area of primary forests has been replaced by secondary forests and logged-over forests [7].

The estimates of forest carbon stocks following disturbance are becoming increasingly important because the degraded forests are one of the crucial components in climate change mitigation actions. The loss of biomass from forest degradation causes the release of large amounts of carbon dioxide into the atmosphere. Therefore, accurate estimates of forest carbon stocks and their changes are essential to calculate carbon emissions resulted from disturbance and to increase the potential of secondary forests in contributing to climate change mitigation strategies.

2. Method

Both literature review and simulation were used in the analysis based on a spatial approach combined with a terrestrial approach (figure 1). A simulation was done using a carbon accounting model [8], as has been used by [9] in modeling carbon emissions and removals from forest lands.

Data used in this study were collated from scientific publications, and official reports from the government agencies working on this topic and the available data were used as a basis for conducting studies on forest degradation and its resulted GHG emissions in Indonesia. Kalimantan Island, which consists of five provinces (i.e., West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan, and North Kalimantan), covering an area of ± 54 million ha, was used as a case study. Spatial data available from various sources within the Ministry of Environment and Forestry including land covers of 2015 and 2016, a burnt area in 2015, forest function, forest concession, and administrative boundaries were used in spatial analysis. Permanent Measuring Plots (known in Indonesian as ‘PUP’) and Periodical Comprehensive Forest Inventory (known in Indonesian as ‘IHMB’) of Kalimantan (Source: BLI-KLHK) used to determine the variation of secondary forest biomass as a terrestrial approach, which was calculated using allometric equation [10], \( AGB = \rho \exp(-1.499 + 2.148 \times \ln(D) + 0.207 \times (\ln(D))^2 - 0.0281 \times (\ln(D))^3) \).
3. Result and discussion

3.1. Indonesia’s GHG Emissions Profile from the Forestry Sector
GHG emissions from the forestry sector were primarily caused by deforestation and forest degradation; if the emissions occur on peatlands, it will be followed by emissions induced from peat. The average area of forest degradation during the period 1990 - 2012 reached 0.51 million ha per year. Nationally, this trend of forest degradation has declined sharply [11]. The average annual emissions from forest degradation for this period was 58 MtCO$_2$e per year, which resulted from the loss of carbon stocks stored in forests. This emission level contributes to 17% of the GHG emissions from the forest sector (excluding peat) (figure 2). However, this level of contribution may be underestimated and contain a high level of uncertainty.

![Figure 2. Indonesia’s GHG Emissions Profile from the Forestry Sector from 1990 to 2012](image)

3.2. Source of the Estimation Uncertainty of GHG Emissions from Forest Degradation
In this study, at least three sources of uncertainty have been identified in estimating GHG emissions from forest degradation that have been reported by the Indonesian government. The sources of uncertainties may include, but not limited to, the definition of forest degradation used in the analysis, scope of activities considered as forest degradation events, and the method used for calculating the emissions.

3.2.1. Definition. Forest degradation is a long process after a disturbance event which then there is the possibility of deforestation. Forest conditions after this disturbance may vary, depending on the frequency, intensity, and type of disturbance. Forest degradation causes changes in the structure and composition of forest vegetation. It will have an impact on the decline in carbon stocks, biodiversity, and the function of environmental services [12]. After the disturbance takes place, the process of natural vegetation succession, new vegetation begins to grow, the remaining vegetation regrowth which allows secondary forests to recover back which may mimic the condition of primary forests, especially in terms of carbon storage. The initial process of forest degradation is the same as deforestation, both of which occur due to forest disturbance which results in the loss of the biomass density resulting in GHG emissions. The difference that occurs is the process after the disturbance occurs, the forest degradation process will occur a recovery (naturally or assisted regeneration) while in the deforestation there will be changes in land use so that the forest will be permanently lost. Considering this condition, analysis of times series data (more than 2-year periods) or the use of other relevant maps is needed to identify forest degradation and distinguish it from deforestation. Different definitions will result in different emissions contributions. The study [9] show that if deforestation is defined as permanent forest loss and forest degradation is analyzed in a time series to see whether there is recovery. Forest degradation contributes more than deforestation to the total of GHG emissions that resulted during the period 2000-2012.

3.2.2. Coverage. The scope of reporting on the results of the quantification of GHG emissions from forest degradation in Indonesia’s FREL (Forest Reference Emission Level) only covers the conversion of primary forests into secondary forests [11]. Forest degradation that occurs in addition to natural
factors is also triggered by several human activities, including logging. Findings on global degradation patterns show that extraction and (commercial) logging activities account for more than 70% of the total degradation in Latin America and (sub)tropical Asia [13]; whereas fuelwood collection activities, charcoal production, have a lower influence on the occurrence of forest degradation [14]. The triggering factors of forest degradation will have a significant influence on changes in forest carbon and the choice of data sources and methods used to measure and monitor forest degradation [13].

Based on our analysis in Kalimantan region on GHG emissions in 2016 caused by disturbance events in 2015 (fires and logging), forest degradation which is only calculated based on the change of primary forest to secondary forest, produces emission estimates that are incomplete and tend to underestimate. As shown in figure 3, the majority of active forest concession areas are identified in secondary forests, so emissions resulted from forest degradation is expected to be higher.

![Figure 3: Active timber concession on a secondary forest in 2015](image)

Primary forests in Kalimantan in 2015 occupied only 18% of the total land cover; in 2016, 99.16% of these primary forests remained as primary forests, and only 0.77% was degraded to secondary forests. On the other hand, secondary forest cover in 2015 reached 31.5% of the total land cover; in 2016, 97.3% of this secondary forest remained secondary forest. However, the analysis shows that 43% of these secondary forests contain forest concessions that are still actively conducting operational logging business (figure 3). This condition has not been captured in the calculation of existing emissions because there are only one secondary forest strata in each forest type on the land cover map. The incidence of forest fires in 2015 in the analysis area did not affect forest degradation because 100% of the burned area was identified occurring in non-forest land, i.e., shrubs, plantations, and agriculture lands.

3.2.3. Accounting method

Indonesia’s GHG emissions reported in the GHG inventory activity from the land-based sector have been estimated using Tier 1 to Tier 2 approaches, i.e., emissions are calculated simply by multiplication of activity data and static emission factor values [15]; studies by [16,17] also used the same approach. Using only a single emission factor in each forest type in the emission estimation will ignore the high variation of secondary forest biomass. Results of our analysis using 18,970 measurement data in Kalimantan show a wide range of biomass density per ha in secondary forests, which ranges 3.6-421.1 tones ha$^{-1}$ in secondary swamp forests and 1.1-547.9 tones ha$^{-1}$ in secondary dryland forests (figure 4).
If the distribution of secondary forest biomass density is grouped into three classes using K-means based on stand volume, it can reduce the standard deviation (table 1). Ignoring the dynamics that occur in biomass after disturbance will result in annual emissions and thus, actual carbon flows that are not adequately described.

**Table 1.** Summary statistics of aboveground biomass (tonnes/ha) in both secondary swamp forest and secondary dryland forests

| Summary Statistic | Secondary Swamp Forest | Secondary Dryland Forest |
|-------------------|------------------------|--------------------------|
|                   | Mean                   | Std Dev                  | Mean                   | Std Dev                  |
| All               | 187.9                  | 82.3                     | 225.7                  | 115.1                    |
| Cluster 1         | 300.3                  | 42.3                     | 404.4                  | 58                       |
| Cluster 2         | 194.7                  | 17.5                     | 249.6                  | 40.6                     |
| Cluster 3         | 106.4                  | 34.9                     | 121.7                  | 42.9                     |

3.3. **Opportunity to Improve its Estimation Accuracy**

3.3.1. **Spatial.** Forest degradation is often challenging to identify because changes may not be seen [18]. However, it can be quantified using a set of criteria and indicators [19], or through remote sensing. Therefore, the remote sensing approach combined with carbon stock field measurement data becomes essential [20]. Remote sensing data supported by field observations is key to effective and efficient monitoring, and it is possible to estimate GHG emissions according to MRV REDD+ needs [21]. Remote sensing data have been widely used for monitoring forest carbon, including optical imagery (Landsat, AVHRR, MODIS) have been used to determine changes in forest cover area [22], as well as Light detection and ranging (LiDAR) and Radar has been used to measure forest carbon density [23] [24]. However, forest and non-forest classification with remote sensing imagery, which is a standard method in the study of deforestation and its impact on the global carbon cycle and climate change [25], cannot be applied to detect forest degradation from logging activities [26].

Remote sensing data are ideal for assessing forest degradation because of its ability to cover a large area, which can separate one pixel in a coarse resolution image (> 1 km) into a percentage of cover for some vegetation types [27]. This concept can also be applied in degraded forests where each pixel consists of tree canopies and open areas. Detection methods using remote sensing data have been used to assess forest canopy density as an indicator of forest degradation [26,28,29]. The use of canopy density using Landsat satellite imagery for degradation detection produces high accuracy and is very promising [30]. However, the detection of degradation using remote sensing data has more significant technical challenges than monitoring deforestation [20,27]. At regional and national scales, methods for detecting and mapping forest degradation using multi-resolution optical imagery, synthetic aperture radar (SAR) and/or LiDAR data have progressively developed. However, there is no single method that can be applied to monitor forest degradation, mainly due to the specific nature of the type or process of degradation and the period observed [31]. Detailed maps of existing land cover, especially on forest
cover by adding strata and canopy den
distances and tree height attributes are an opportunity to improve the
accuracy of GHG emissions estimates from forest degradation.

3.3.2. Accounting method
Understanding various approaches to estimate GHG emissions, and how this affects the magnitude of
the flux of the GHG component, is the first important step towards the reconciliation of GHG inventories
[32]. In Indonesia’s current GHG emission reports, the GHG inventory activities from the land-based
sector have been carried out applying Tier 1 to Tier 2 approaches, on the other hand several other
countries such as Canada, Australia, Mexico have developed a tier 3 carbon accounting model, based
on a system approach or carbon balance to describe the actual conditions that occur in forests [33]. Some
tools have been developed to estimate carbon flow in relation to the GHG emissions calculation. Full
Carbon Accounting Models (well known as FullCAM), is one of the software developed to calculate
forest carbon by calculating the carbon cycle that occurs in forests [8]. Simulation models of forest
degradation using FullCAM can be seen in figure 5.

![Figure 5. Carbon flow of forest degradation on model simulation](image)

4. Conclusion
This study clearly shows the importance of calculating GHG emissions from forest degradation caused
by anthropogenic activities (logging, fires). It is recommended that uncertainty levels of GHG estimates
from forest degradation can be reduced by the existence of clear and verifiable definitions, detailed land
cover maps, and accurate estimation. Accuracy of the estimates can be improved using a system
approach that occurs in the carbon cycle of ecosystems through modeling to capture flows of carbon
after the disturbance events.

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