Climate Change Agent: An Evidence from Deforestation Model in Indonesia

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Abstract. In this study, model of deforestation is expressed as a function of the direct causes, each of these expressed as a function of the indirect causes. The socio-economic growth variables, such as population and GDP growth, were used as indirect causes of deforestation. The model assumed that deforestation was caused by wood consumption, forest product export, conversion to cropland, and forest fire. This study also calculated the elasticity of forest fire deforestation with respect to the population based on forest fire data between 1991 and 2000. Finally, it analysed the carbon emissions due to deforestation rate in Indonesian forest.

1. Introduction
Indonesia has around 10% of the world's remaining tropical forest, which, in 2010, had a total forest area of 113 million ha [1]. From 2001 to 2015, 89% of tree cover loss occurred in Indonesia where the dominant driver of the loss was permanent deforestation. In the year 2017, Indonesia has had a success in decreasing the rate of its deforestation up to 60% of the tree cover loss in primary forests compared with 2016 which equal to 0.2 giga tonnes of carbon dioxide, or about the same emissions released from burning over 199 billion pounds of coal. Meanwhile, the rest of rate of deforestation were caused by forest fires in 2015, which were affected by climate-driven drought [2]. Thus, the diverse natural forests and peat land were destroyed permanently, disturbing wildlife populations and alienating indigenous people from their inherited lands.

It has been estimated that the rate of deforestation ranged from 1.3 to 2 million ha per year [3]. Logging was assumed to be the cause of deforestation, which was not done through clear-cutting, but by facilitating entry and clearing by shifting cultivation [4]. Often deforestation was associated with settlement of the official transmigration sites and the establishment of large plantations company for oil palm or pulpwood. The remaining caused of the deforestation were attributed to shifting cultivation which often presumed to be subsistence-oriented. Shifting cultivation in Indonesia, however, encompasses more than just subsistence or food crops. There are shifting cultivation systems which include both staple crops and export-oriented tree products. For instance, in some low population density areas, coffee is grown by shifting cultivators, who abandon plots after six or seven years due to the declining yields [5]. Hence, this paper will analyse the climate change impact through the model of deforestation in Indonesia. It will use population and economic growth as the driving forces of deforestation.

2. Deforestation Model
The causes of tropical deforestation could be classified into two classes. The first-class (or direct) causes are grouped into two categories, i.e., pressure for forest products (for consumption and exports) and
pressure on forest land alternative (cropland) land uses. The second-class (or indirect) causes of deforestation are population, gross domestic product, external debt and government policies. The rate of deforestation is expressed as a function of the direct causes; each of these has previously been expressed as a function of the indirect causes. Kant and Redantz’s [6] model assume that deforestation is caused by roundwood consumption, export of forest products, conversion to cropland, and conversion to pasture land. The econometric model of tropical deforestation has been modified and applied to Indonesia’s deforestation case. For detail description, see Kant's and Redantz [6].

The rate of conversion from forest to cropland (including transmigration and infrastructure development) was 1.32 million ha per year until 2010 as reported by the Ministry of Environment and Forestry [7]. The model has extrapolated the rate to increase up to 938,560 ha per year by assuming 1.2% annual rate of increase during 1990 – 2000 [8]. Boer et al., [9] identified that agriculture development was the main cause of deforestation in Indonesia. Roundwood consumption and forest products export also increased the rate of deforestation after agriculture development. Deforestation rate due to roundwood consumption was 67 million m$^3$. Later, deforestation from forest product export was around 34,000 m$^3$ per year. In addition, it has been substituted that forest conversion into pasture land was the direct cause of deforestation along with forest fire, which occurred mostly every year in Indonesia. Forest fires have also caused much damage to the Indonesia’s economy and environment. The causes were largely due to land use changes, such as shifting cultivation and cropland conversion [10]. Most fires were mainly occurred in agricultural lands rather than in forested lands [11]. Based on the 1982-2017 forest fire data, the average area affected by forest fire was about 12,000 ha annually. Meanwhile, in the El-Niño years, the burnt area surmounted to 44,000 ha. In 2015, Indonesia experienced the largest forest fire ever in the world, with burnt area totalling to 261,060 ha [12].

To simplify, the model has chosen the first-class (direct) causes of deforestation in Indonesia as those related to roundwood consumption, export of forest products, change in cropland and forest fire. In addition, understanding the linkages between the first-class (direct) causes and the second-class (indirect) causes are also important. The model calculated the elasticity ($e$) of deforestation ($D_t$) with respect to the population ($P_t$) as function of $e = \left( \frac{\delta D_t}{D_t} \right) \left( \frac{\delta P_t}{P_t} \right)^{-1}$ and GDP growth ($G_t$) also as function of $e = \left( \frac{\delta D_t}{D_t} \right) \left( \frac{\delta G_t}{G_t} \right)^{-1}$ for Indonesia, based on deforestation data. This paper would expand in two ways. First, the model took into account forest fire as the cause of deforestation with respect to the population. In the original model [13], the model assumed that forest fire deforestation falls gradually over time, because of an increasing effort in forest fire prevention. Second, the model simulates the indirect causes of deforestation (population, gross domestic product) with three different trajectories to reflect future demographic [14, 15] and socio-economic development uncertainty.

The deforestation model is described below:

$$D_t = D_t^{\text{roundwood}} + D_t^{\text{export}} + D_t^{\text{cropland}} + D_t^{\text{fire}} \tag{1}$$

with

$$D_t^{\text{roundwood}} = \left( \frac{P_t}{P_{t-1}} \right)^{0.6509} D_{t-1}^{\text{roundwood}} \tag{2}$$

$$D_t^{\text{export}} = \left( \frac{Y_t^W}{Y_{t-1}^W} - 1 \right)^{0.0668} D_{t-1}^{\text{export}} \tag{3}$$

$$D_t^{\text{cropland}} = \left( \frac{Y_t}{Y_{t-1}} - 1 \right)^{0.6171} D_{t-1}^{\text{cropland}} \tag{4}$$
\[ D_t^{\text{fire}} = \left( \frac{P_t}{P_{t-1}} \right)^{0.0434} D_{t-1}^{\text{fire}} \]  

where

- \( D_t \) = total deforestation in year \( t \)
- \( D_t^{\text{roundwood}} \) = deforestation for roundwood consumption in year \( t \)
- \( D_t^{\text{export}} \) = deforestation for forest products export in year \( t \)
- \( D_t^{\text{cropland}} \) = deforestation for cropland in year \( t \)
- \( D_t^{\text{fire}} \) = deforestation due to forest fire in year \( t \)
- \( P_t \) = total population of Indonesia in year \( t \)
- \( Y_t^{\text{world}} \) = total GDP worldwide in year \( t \)
- \( Y_t \) = GDP of Indonesia in year \( t \)

Population and economic growth were the driving forces of deforestation. The model used historical and projected population data from UN [16]. These data were the expression of population data projection from 2000 to 2050 with three different variations: low, medium, and high. The GDP data for Indonesia are taken from the AIM model [17]. The model extrapolates the population and GDP data projection for the next year to 2100 based on the growth rate from the previous data. Table 1 shows total growth between 2000 and 2100 for the four scenarios. These scenarios followed the IPCC Special Report on Emission Scenarios (SRES) as written in IPCC, 2000 and four SRES scenarios (A1B, A2, B1, and B2) were selected. This research is using SRES based on driving forces from demographic to social and economic developments, that encompass a wide range of future greenhouse gas (GHG) emissions. These scenarios were chosen, because it directly considers the socio-economic growth factor [18].

Table 1. Total growth of population and GDP between 2000 and 2100 (resume for Indonesia).

| Set           | A1B    | A2    | B1    | B2    |
|---------------|--------|-------|-------|-------|
| Population growth (% per year) | 0.14   | 0.87  | 0.14  | 0.59  |
| GDP growth (% per year)         | 4.08   | 3.03  | 3.63  | 3.07  |
| Per capita GDP growth (% per year) | 3.93   | 2.15  | 3.48  | 2.46  |

3. Results and Discussion

In the year 2000, the deforested area in Indonesia caused by forest fire was 35,497 ha per annum. In the model, the resulting deforestation due to forest fire was given in Figure 1. In the A1B and the B1 scenarios, as population increased, the forest fire-triggered deforestation increased from 35,497 ha in 2000 to 35,900 ha annually until 2050, then would decrease gradually to 35,700 ha annually in 2100. These scenarios were based on the low population projection. The highest population trajectory in Indonesia would drive forest fire-triggered deforestation to increase to 36,900 ha annually to 2100. For the median population projection, in the B2 scenario, Indonesia’s deforestation caused by forest fire increased to 36,400 ha per year in 2100 (Figure 1).
Figure 1. Deforestation rate by forest fire.

On the other hand, the model assumed that the B2 scenario is the reference scenario with the medium population and economic development projection. In Figure 2, cropland was the main contributor of the total rate of deforestation forming 45% of the total deforestation in 2000; this decreased to 39% of the total deforestation, corresponding to about 857,200 ha per year in 2100. Forest product export was the second contributor to deforestation, with 34% of the total deforestation in 2000, and slightly decreased to 32% of the total deforestation in 2100. Deforestation by roundwood consumption increased gradually from 422,240 ha per year (20% of total deforestation) in 2000 to 28% of the total deforestation in 2100 (Figure 2). It was estimated that forest fires contribution to deforestation was minor [19,20,21].

Figure 2. Percentage of deforestation for reference scenario (B2 scenario).
Figure 3 considers the rate of deforestation with various scenarios. In the A1B and the B1 scenarios, the rate of deforestation appeared similar, except for the rate of deforestation by cropland. In the A1B scenario, the rate of cropland deforestation was higher than in the B1 scenario. Even if the population growth as the driver of deforestation was the highest within the A2 scenario, however, the economic development has experienced the lowest growth, causing the rate of deforestation to a slight decreased in the first half of century in million tonnes of C, which later increased to the end of the century as an implication of population development (Figure 3).

![Figure 3. Total deforestation with various scenarios.](image)

In the B2 scenario (reference scenario), deforestation increased slightly to the first half of century and decreased slightly to the end of the century, but still higher than the A1B and B2 scenarios (Figure 3). Figure 4 shows the corresponding emissions of carbon dioxide (left-hand axis) and difference of carbon emission from the A1B, A2, and B2 scenarios as compared to the B2 scenario (right-hand axis).

![Figure 4. Carbon emission from deforestation.](image)
As shown in the figure above, by using each scenario to determine the carbon emissions, showed that deforestation gave a significant effect into the rate of carbon emissions. Meanwhile, with the assumption that the unit factor of 1 ha of tree cover could store approximately 96 tonnes of carbon emission, the loss by deforestation as projected in 2100 was equivalent to 82 million tonnes carbon per year. Therefore, it could be taken as a premise that deforestation is one of climate change agents, if it could not be reduced significantly.

4. Conclusions
In this paper, we developed the model of deforestation in Indonesia as the implication of future demographic and socio-economic development. The projection of deforestation levels for the year 2000 to the year 2100 were based on the four SRES scenarios A1B, A2, B1 and B2 (differ with respect to population and GDP growth). The indirect causes of forest fires related to population was found to be highest in the A2 scenario with the average Indonesian population growth rate of 0.87% per year over the period of 100 years. Our scenario projections indicated that economic development has led cropland as the main contributor of deforestation, higher than other causes of deforestation. In the A1B scenario, the rate of deforestation was initially higher than other scenarios but later decreased gradually. Emissions of carbon dioxide from deforestation have been high and continue to be unabated, making the country a potentially big targets for projects under CDM (clean development mechanism). Indonesia should consider decreasing carbon dioxide emissions by slowing deforestation rate.

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