CO_2 EMISSIONS FROM FOREST CLEAR CUT IN ROAD CONTRUCTION PROJECT

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ABSTRACT: Major sources of CO_2 release caused by anthropogenic activities include fossil fuel combustion, cement production, and forest clear cut. The first two sources have been recognized as important in the construction industry; efforts have been made to find the causes of and the solutions to the emissions in the fuel combustion and cement production. However, the third major source−forest clear cut−has not yet received its deserving attention in the construction industry, although it may be one of the most important source of CO_2 release in various infrastructure projects such as road construction. This study presents a methodology to calculate the amount of CO_2 release from forest clear cut in a road construction project. An actual road construction in Korea was used as a case study for quantifying the CO_2 release. First, the forest area was divided to three categories (biomass carbon stocks, carbon stocks in dead organic matters, and carbon stocks in soils) depending on the source of CO_2 emission, as suggested by IPCC (International Panel on Climate Change). Second, for each category, a methodology was derived to estimate the CO_2 emission amount using the gain-loss analysis. Finally, the CO_2 emissions from the forest clear cut were compared to those from the fuel consumption by equipment usage in the same case to understand their relative magnitude in CO_2 emissions. The study results are expected to be used as a basis for development of CO_2 emission reduction strategies in road construction.

Keywords: *Road Construction, Forest Clear Cut, CO_2 Emissions or GHG*

1. INTRODUCTION

Since the Kyoto protocol announcement, ever increasing interests and concerns have been shown for greenhouse gas (GHG) emissions. A consensus has been being formed that the GHG emissions bring about the greenhouse effect [1], which leads to unprecedented climate events. Extremely high or low temperatures, severe rain storm and floods, and sea level changes are some examples that are considered to be attributed by climate changes.

CO_2 is attributed to 70% of the ongoing greenhouse effect [2]. The major sources of the CO_2 release by anthropogenic activities include fossil combustion, cement production, and forest clear cut [3]. In construction industry, the first two sources (fossil combustion and cement production) have been recognized as important and efforts have been made to find the causes of and the solution to the emission. However, the third source (forest clear cut and forest land use change) has not yet received its deserving attention, although it may be the most important source of CO_2 release. Particularly, in road construction that takes place over a wide range of area, the deforestation, including forest clear cut and land use change, has a big potential to impact the climate change.

The primary objective of this study was to estimate the level of CO_2 generated from deforestation by road construction. In this paper, a literature review is first presented to discuss previous research efforts for understanding GHG emissions in road construction. A methodology is then derived to rationally estimate the GHG emissions in road construction. Finally, a case study was conducted to understand the relative magnitude of the CO_2 emission compared to that of equipment usage in road construction. Findings and recommendations are also presented.

2. LITERATURE REVIEW AND RESEARCH OBJECTIVES

Studies have been conducted to estimate environmental impact of road construction. Hendrickson and Horvath [4] developed a life cycle assessment model for pollution emissions from major U.S. construction sectors, based on each sector`s resource inputs. Stripple [5] performed a life cycle inventory analysis of road construction project in Sweden in order to determine total energy consumption of road construction. Park et al. [6] estimated environmental loads from highway life cycle in Korea. Santero and Horvath [7] expanded the previous list of lifecycle components to include eight components of global warming potential of pavements. For estimating environmental impact of forest clear cut, California Energy Commission [8] examined the total carbon emissions from forest in Shasta County, California, USA.

As shown in the previous studies, environmental effects of GHG release from forest clear cut have been relatively overlooked in the field of road construction. As a result, an accurate way to estimate global warming effect from deforestation by road construction has not yet been included in life cycle assessment of road construction. Studies such as the one conducted by California Energy Commission [8] provided ways to estimate GHG emissions of deforestation for a vast geographical area. However, it has not yet been clear as to how much impact a road construction project would have on GHG emissions. In other words, a methodology is needed to estimate the GHG emissions caused by road construction at the project level. As a result, a practical way to reduce the GHG emission in road construction could be devised.

The main objective of this research was to develop a methodology to estimate the total GHG emissions caused by forest clear cut in road construction at a project level. The development procedure of the methodology is detailed in the following sections.

3. METHODOLOGY

3.1 BASIC ASSUMPTIONS

As previously mentioned, CO_2 emissions from forest clear cut or land use change is a major source of the greenhouse effect. Thus, this study was focused on the role of deforestation for carbon cycle. This study was predicated that the forest area converted into road would last forever, that is, the road converted from the forest area would remain as the road permanently. In addition, this study was based on the assumption that the area of each construction project is a system that has a clear boundary. In other words, inputs and outputs can be defined by measuring the flow of carbon components into or from the project system. For example, the biomass of woods that are cut during the deforestation does not promptly emit its corresponding CO_2 amount to atmosphere. However, since the biomass of the removed woods is considered as output from the project system, it is included in the total CO_2 emissions. The area of deforestation, which indicates the system boundary, is given by the planning and design documents of the project.

3.2 CALCULATION METHODOLOGY

International Panel on Climate Change (IPCC) provided a guideline [9] that has been used to assess biomass inventory. In this study, the concept of the guideline was used to estimate CO_2 emissions from deforestation in road construction. This concept can be summarized as the gain-loss method; total carbon stock change is a difference between increasing carbon stocks and decreasing carbon stocks. As previously mentioned, it was assumed that once a road was constructed, it remains that way forever. Thus, it is rational to regard the carbon stock change occurred during the road construction as the permanent CO_2 emission amount.

Carbon stock in forest was classified into three categories: biomass carbon stock, carbon stock in dead organic matters, and carbon stock in soil. Biomass carbon stock was the amount of carbon stored in the volume of woods that were cut. Carbon stock in dead organic matters was the biomass in dead woods or litter; here, the dead organic matters were larger than minimum diameter limit (2mm) [9]. Third, carbon stock in soil was a carbon held within the soil and dead organic matters that were less than minimum diameter limit (2mm) [9].

In this study, other GHGs were also considered. For example, CH_4 has 23 times of global warming potential and N_2O has 296 times of global warming potential compared to that of CO_2 [8], however, CH_4 and N_2O are emitted mainly as the result of anthropogenic activities such as fertilization of land [10] and forest fires [9]. Therefore, Non-CO_2 emission, such as CH_4 and N_2O, was excluded in our research scopes.

The total change of carbon stocks from forest clear cut in road construction can be expressed as a sum of change among the three categories, as shown in Eq. (1):

$$\Delta C = \Delta C_B + \Delta C_{DOM} + \Delta C_{Soil} \qquad (1)$$

where, ΔC is the total change in carbon stocks from forest clear cut (unit = $t\,CO_2\,e$); ΔC_B is the change in carbon stocks in biomass (above- and below-ground woods biomass) (unit = $t\,CO_2\,e$); ΔC_{DOM} is the change in carbon stocks in dead organic matters (dead wood and litter) (unit = $t\,CO_2\,e$); ΔC_{Soil} is the change in carbon stocks in soils (unit = $t\,CO_2\,e$).

Biomass carbon stocks

The first term of the right-hand side of Eq. (1) presents carbon stocks in above- and below-ground woods. IPCC suggests a way to calculate this term as a sum of biomass carbon loss due to wood removal, fuel-wood removal, and disturbance such as fire [9]. In this research scope, only wood removal was considered for the biomass carbon loss, because only it is the most likely situation in road construction. For the calculation of biomass carbon stocks caused by wood removal is shown in Eq. (2):

$$\Delta C_B = V \times D \times BEF \times R \times CCF \qquad (2)$$
$$= m^3 \times \frac{\text{tones}}{m^3} \times \frac{\text{tones}}{\text{tones}} \times \frac{\text{tones}}{\text{tones}} \times \frac{tCO_2\,e}{\text{tones}}$$

where, ΔC_B is the change in carbon stocks in biomass (above- and below-ground woods biomass) with a unit of $t\,CO_2\,e$; V is the total merchantable growing stock; D is the basic wood density; BEF is a biomass expansion factor for merchantable stock biomass' expansion to above-ground biomass; R is ratio of the total biomass (including below-ground biomass) to above-ground biomass; CCF is carbon conversion factor.

For calculating the total merchantable growing stocks (V), the necessary data were derived from a report produced by Korea Forest Service (KFS) [11]. Densities (D) (dry matters' weight to volume of wood) were 0.47 and 0.8 for coniferous forest and for broadleaved forest [12], respectively. The ratios of R were given values of 1.28 for coniferous forest and 1.41 for broadleaved forest [12], respectively. For the carbon conversion factor (CCF), 0.51 and 0.48 were chosen for coniferous forest and for broad leaved forest [13], respectively; CCF is a multiplier that transforms the biomass into tCO_2e.

Carbon stocks in dead organic matters

The second term of the right-hand side of Eq. (1) presents carbon stocks in dead organic matters. "Dead organic matter (DOM) comprises dead wood and litter [9]." Dead wood includes all non-living woody biomass such as remaining roots after felling [9]. Litter includes dead organic matter such as fallen leaves due to change of seasons. Carbon stock change in DOM during a road life cycle is shown in Eq. (3):

$$\Delta C_{DOM} = A \times \left[\left(DW_{t1} - DW_{t2} \right) + \left(LT_{t1} - LT_{t2} \right) \right] \qquad (3)$$
$$= \text{ha} \times \left[\left(\frac{tCO_2\,e}{\text{ha}} - \frac{tCO_2\,e}{\text{ha}} \right) + \left(\frac{tCO_2\,e}{\text{ha}} - \frac{tCO_2\,e}{\text{ha}} \right) \right]$$

where, ΔC_{DOM} is change in carbon stocks in dead wood or litter with a unit of $t\,CO_2\,e$; A is the area of managed forest; DW_{t1} is the carbon stocks in dead wood per unit area at time t_1; DW_{t2} is the carbon stocks in dead wood per unit area at time t_2; LT_{t1} is the carbon stocks in litter per unit area at time t_1; LT_{t2} is the carbon stocks in litter per unit area at time t_2; t1 is the commencement time of construction; t2 is the time at the end of the road life cycle.

The carbon stocks in DOMs at time t2, DW_{t2} and LT_{t2} , can be estimated to have a value zero, because the road is considered to have a sufficiently long life cycle. It was also assumed that the target forest was not affect by large-scale felling or other extreme disturbances such as severe disasters. Based on this assumption, the factor of dead wood, DW_{t1} , was naturally ignored in this term. IPCC suggested a default value for carbon stock in litter per unit area at time t1 according to forest type and climate. 28.2 tonnes C ha^{-1} for broadleaf deciduous forest and 20.3 tonnes C ha^{-1} for needle leaf evergreen forest [9] were used for LT_{t1} .

Carbon stocks in soils

There are many uncertainties in estimating carbon stocks in soil because organic carbon content depends on the forest type and climatic conditions [14]. However, soil carbon stocks could not be neglected because soil carbon stocks constitute a big portion of CO_2 existence on the surface of the earth; globally, soil carbon stock of mineral soil only is estimated approximately 700 P g C [15].

Carbon stocks in soil is estimated as in Eq. (4):

$$\Delta C_{Soil} = A \times \left(SOC_0 - SOC_t \right) \leq A \times SOC_0 \qquad (4)$$
$$= \text{ha} \times \left(\frac{\text{tCO}_2\text{ e}}{\text{ha}} - \frac{\text{tCO}_2\text{ e}}{\text{ha}} \right)$$

where, ΔC_{Soil} is the change in carbon stocks in soils with a unit of $t\,CO_2\,e$; A is the area of forest change; SOC_0 is the soil organic carbon stocks per unit area at the beginning of deforestation; SOC_t is the soil organic carbon stocks per unit area at time t; t - 0 is a period for the soil organic value to be stabilized into equilibrium (20 years are commonly used). SOC_0 was estimated to be 67.9 in Korea [12].

4. CASE STUDY

4.1 CASE DESCRIPTION

This study selected a case which involves a typical road construction in Korea for estimating CO_2 emissions from forest clear cut. Since most of Korea is composed of mountain or hill areas, the case in Korea was considered to be suitable for understanding how much CO_2 emissions from deforestation due to road construction were generated.

Table 1. Case study description

Category	Basic Information
Location	Jeolla-do, Korea
Design speed (km/hr)	80
Width (m)	20.0
Number of lanes	4
Length (km)	7.380
Commencement of work	2004.11
Total direct cost (US$)	74,762,087
Forest area (m^2)	252,292

As shown in Table 1, the forest-removal area was 25.292 ha. Sixty nine percent of the forest change area consisted of coniferous forest, whereas 31% was composed of broadleaved forest [11]. The number of trees which were cut during this project was estimated about 18,000 trees. All supporting data were based on the planning and design documents for the project.

4.2 RESULTS

According to the aforementioned methodology, the total amount of CO_2 emissions caused by forest clear cut was estimated. The amounts of CO_2 emissions for the three sources are shown in Table 2.

Table 2. CO_2 release in forest clear cut

Source of CO_2 release	Type of tree	CO_2 emissions (tCO_2e)
Biomass carbon stocks	coniferous forest	739.74
	broadleaved forest	464.56
Carbon stocks in dead organic matters	coniferous forest	353.39
	broadleaved forest	220.55
Carbon stocks in soils		≤ 1713.06
Total		1778.24 ~ 3491.3

The minimum value was calculated based on the assumption that the SOC_t (soil organic carbon stocks per unit area at year 20) was the same as SOC_0, while the maximum value was obtained assuming that SOC_t was zero. This was done to show the whole range of CO_2 emissions, including the best and the worst scenarios. The total CO_2 emissions from forest clear cut due to the road construction was estimated between 1778.24 tCO_2 e (minimum) and 3491.3 tCO_2e (maximum).

As shown in Table 2, two thirds of the total minimum CO_2 emission resulted from the biomass carbon stocks and the remaining one third was from the carbon stock in DOM matters. For comparison purpose, the CO_2 emission amount (8678.01 tCO_2e,) from on-site equipment usage for the same road construction [16], was compared with the CO_2 emission from forest clear cut. It is worth noting that the forest clear cut produced 20 to 40% of the CO_2 emission amount of those from the onsite equipment operation. This indicates that forest clear cut produces a high level of CO_2 emission and can significantly impact climate change.

5. UTILIZATION OF THIS STUDY RESULTS

The CO_2 release from deforestation in road construction was estimated at a project level. These results would help project participants or project managers analyze global warming effect of forest clear cut at a project level of construction. The following benefits are expected:

- The important source of GHG emissions−forest clear cut−is not able to be added to the life cycle assessment of road for more accurate analyses.
- The proposed methodology could be used as an indicator for landscape planning. Project managers or planners can easily predict environmental impacts caused by deforestation due to road construction. For example, the result of this study can be used to offer trade-off analyses for understanding how many trees should be planted or how much cost should be paid for environmental cost for the project.

6. CONCLUSIONS

This paper provided a comprehensive methodology to estimate the total CO_2 emissions by forest clear cut and forest use change from road construction at a project level. The proposed methodology was developed considering the characteristics of deforestation by road construction, based on the IPCC guidelines. A real-life road construction project in Korea was selected as a case study to verify the proposed methodology. The case study showed that the proposed methodology could successfully measure the CO_2 emission amount, and that forest clear cut during road construction was a significant source of CO_2 emission.

Future studies are required to refine the proposed methodology. A parametric approach is desirable such that the proposed method can predict the total CO_2 emission due to deforestation in an early stage of road construction. For example, depending on the type of the road, CO_2 emission per unit length can easily be calculated to assist government officials or project planners in analyzing environmental costs. The early and accurate quantification of environmental cost will lead to more sustainable road construction.

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