ASSESSMENT OF GREENHOUSE GAS EMISSIONS FROM ROAD CONSTRUCTION

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Hyoungkwan Kim, PhD, PEng
Yonsei University

Contents

- Byungil Kim, Hyounkyu Lee, Hyung Bae Park, and Hyoungkwan Kim (2012). "Greenhouse Gas Emissions from Onsite Equipment Usage in Road Construction" Journal of Construction Engineering and Management, 138(8), 982—990.
- Byungil Kim, Hyounkyu Lee, Hyung Bae Park, and Hyoungkwan Kim (2012). "A Framework for Estimating Greenhouse Gas Emissions Due to Asphalt Pavement Construction" Journal of Construction Engineering and Management, 138(11), 1312—1321.
- Byungil Kim, Hyounkyu Lee, Hyung Bae Park, and Hyoungkwan Kim (2013). "Estimation of Greenhouse Gas Emissions from Land-Use Changes Due to Road Construction in the Republic of Korea" Journal of Construction Engineering and Management, 139(3), 339—346.

Greenhouse Gas Emissions from Onsite Equipment Usage in Road Construction

Research Needs and Objectives

- According to the National Institute of Environmental Research (2009), air pollutant emissions from onsite construction equipment account for 6.8% (253;058⁄year) of the overall emissions produced in Korea.
- However, GHG emissions from onsite equipment usage during the construction phase have not been fully investigated.
- It is not clear which work type, equipment, or activity is the main source of emissions from onsite equipment during construction.
- The main objectives of this study were to estimate the levels of GHG generated by various equipment types during different construction activities, to identify major emission sources of onsite equipment, and finally to provide a reduction method for such sources.

Basic Premises

- This study is predicated on the fact that GHG emissions from onsite equipment usage during construction are directly related to the energy consumption of the equipment.
- That is, energy consumption increases in direct proportion to the working hours of the construction activities. Working hours were calculated from design documents including quantity takeoff and unit pricing data.
- Meanwhile, this study considered only three GHGs—carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O)—in the GHG selection because they account for 98.9% of the entire GHG emissions (Matin et al. 2004).

Calculation Methodology

$$H_i^j = \frac{X^j}{Q_i^j} = \frac{X^j}{q_i^j \times n_i^j \times f^j \times e_i^j} = \frac{\text{m}^3}{\frac{\text{m}^3}{\text{cycle}} \times \frac{\text{cycle}}{\text{hour}} \times \% \times \%} \quad (1)$$

where H_i^j = the working hours of equipment i for activity j, X^j = the total quantity for activity j, Q_i^j = the quantity per unit time of equipment i for activity j, q_i^j = the quantity per one cycle of equipment i for activity j, n_i^j = the cycle of equipment i per unit time for activity j, f^j = the soil conversion factor for activity j, and e_i^j = the production efficiency of equipment i for activity j.

Calculation Methodology (cont'd)

$$E_i^j = H_i^j \times C_i = \text{hour} \times \frac{\text{liter}}{\text{hour}} \qquad (2)$$

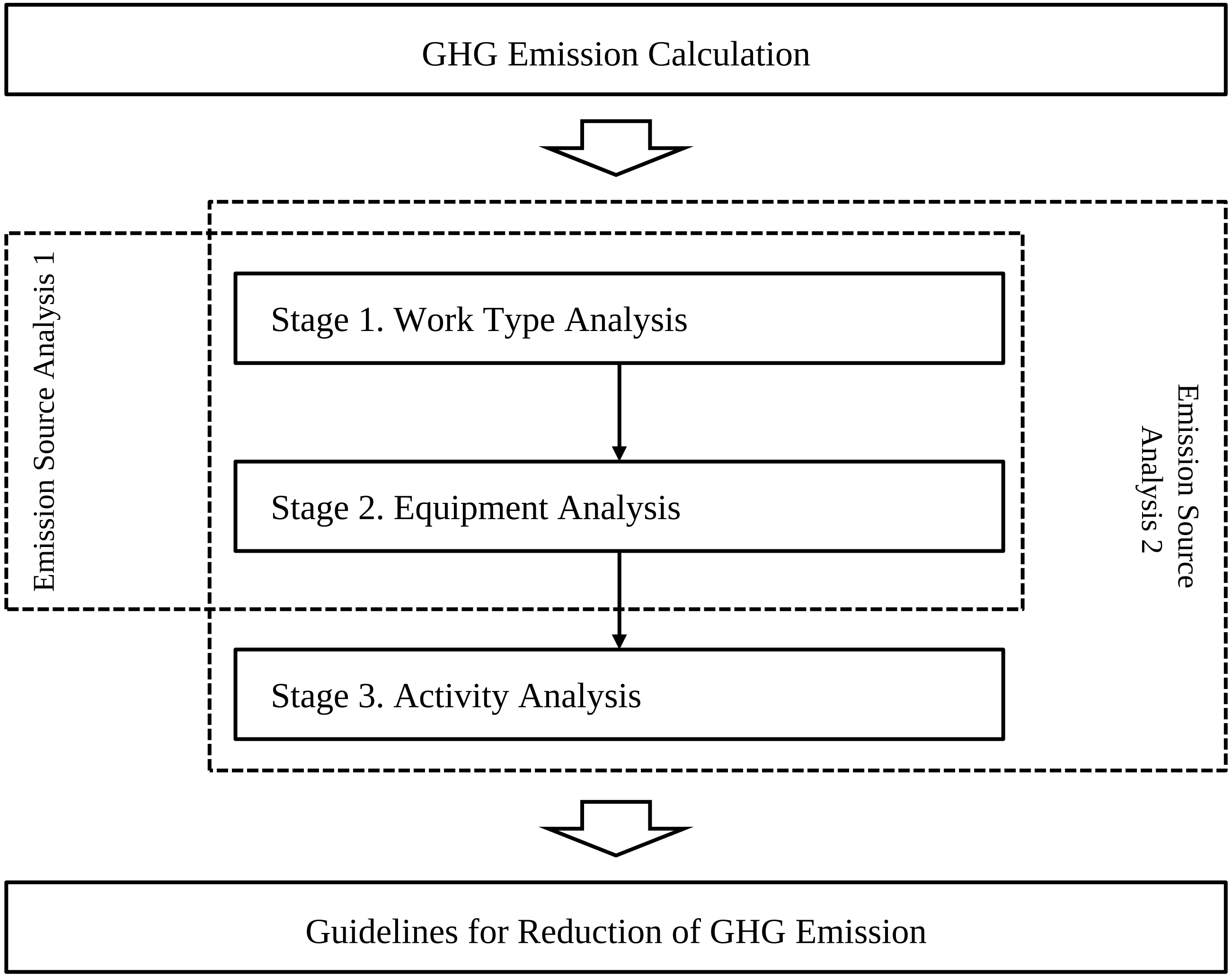
where E_i^j = total energy consumption of equipment i for activity j and C_i = the energy consumption of equipment i per unit time.

Calculation Methodology (cont'd)

$$CO_2e_i^j = E_i^j \times OCF_k \times CEF_k \times RMW$$
$$= \text{liter} \times \frac{\text{TOE}}{\text{liter}} \times \frac{\text{carbon}}{\text{TOE}} \times \frac{44}{12} \tag{3}$$

where $CO_2e_i^j$ = the global warming effect of equipment i for activity j, OCF_k = the oil conversion factor of fossil fuel k, CEF_k = the carbon emission factor of fuel k, RMW = the ratio of the molecular weight of carbon dioxide (44) to the molecular weight of carbon (12), and TOE = the tons of oil equivalent specified by the International Energy Association. The values of OCF_k and CEF_k are from the IPCC (2007).

Overview of Research Procedure



Case Description

- Emission source analysis 1: Two road construction projects were used.

Table 2. Basic Information about the Highway Constructions

Category	Case 1	Case 2
Location	Jeolla-do, Korea	Jeolla-do, Korea
Design speed (km/h)	100	100
Width (m)	20	20
Number of lanes	4	4
Length (km)	10.137	8.744
Commencement of work	October 23, 2003	August 28, 2003
Unit cost (dollars/lane-km)	2,127,657	858,759

- Emission source analysis 2: Additional 22 road construction projects were used.

Energy Consumption of Equipment

Table 1. Energy Consumption of Equipment

Equipment	Capacity		Fuel consumption (L/h)	Fuel type
Asphalt distributor	3,800	L	10.9	Diesel
Asphalt paver finisher	3	m	13.0	Diesel
Bulldozer	19	t	25.0	Diesel
	32	t	41.6	Diesel
Concrete finisher	105.9	kW	10.6	Diesel
Concrete pump car	41	m	23.3	Diesel
Concrete saw	320–400	mm	5.6	Gasoline
Concrete vibrator	0.75	kW	1.0	Diesel
Crane	10	t	3.8	Diesel
	15	t	4.7	Diesel

⋮

Greenhouse Gas Emissions from Equipment Usage

Table 3. Greenhouse Gas Emissions from Equipment Usage (tCO_2e/lane-km)

Work type	Equipment	Work hour	Energ consum
Earthwork	Bulldozer 19 t		
	Bulldozer 32 t	1,637.5	68,11
	Crane 40 t	72.3	83
	Crane 50 t	255.2	3,06
	Dump truck 06.0 t	17.2	13
	Dump truck 15.0 t	14,254.1	226,64
	Excavator 0.7 m^3	132.7	1,53
	Hydraulic ripper 32 t	213.3	8,87

⋮

Guidelines for Reducing Greenhouse Gas Emission

These guidelines can be generalized for road construction sites:

- Clear the land before conducting main activities;
- Take advantage of downgrade operations;
- Combine the functions of more than one equipment for a synergistic effect; and
- Choose the proper type of equipment components for the specific site conditions.

Conclusions

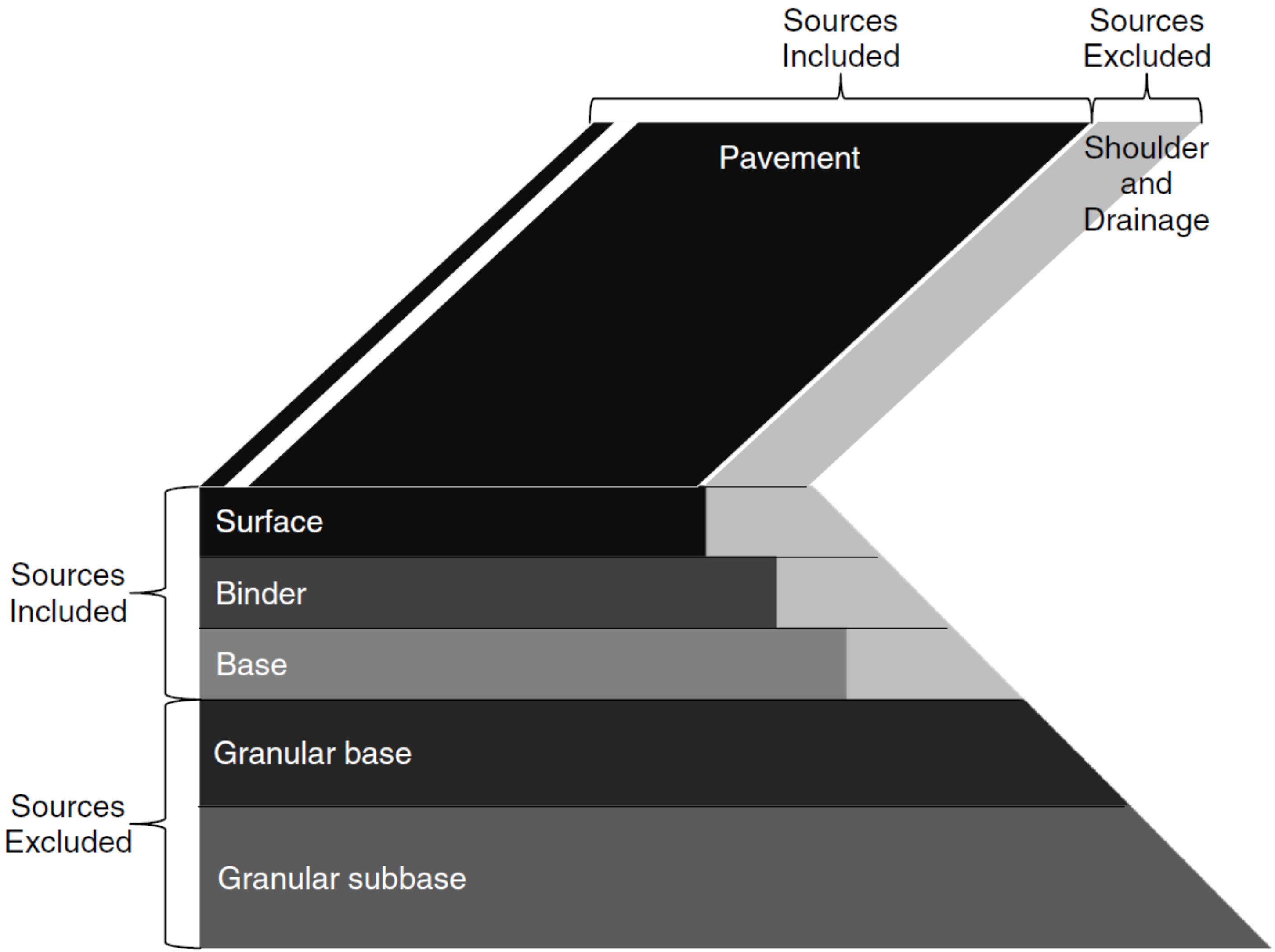
- Based on the design documents of 24 cases, greenhouse gas emissions from onsite equipment usage for different activities were estimated.
- Results showed that earthwork produced the largest percentage of GHG emissions, more than 90%, among all of the work types.
- The average of GHG emissions were estimated at 429.68 tCO_2e.
- Dump truck, bulldozer, and loader were, in decreasing order, the major sources for such emissions.
- In terms of GHG emission potential, eight activities (excavation of topsoil, weathered rock, and rock; transportation of topsoil, weathered rock, and rock; and embankment of subgrade and road bed) were identified as the major activities, representing approximately 80% of the total GHG emission in earthwork.

A Framework for Estimating Greenhouse Gas Emissions Due to Asphalt Pavement Construction

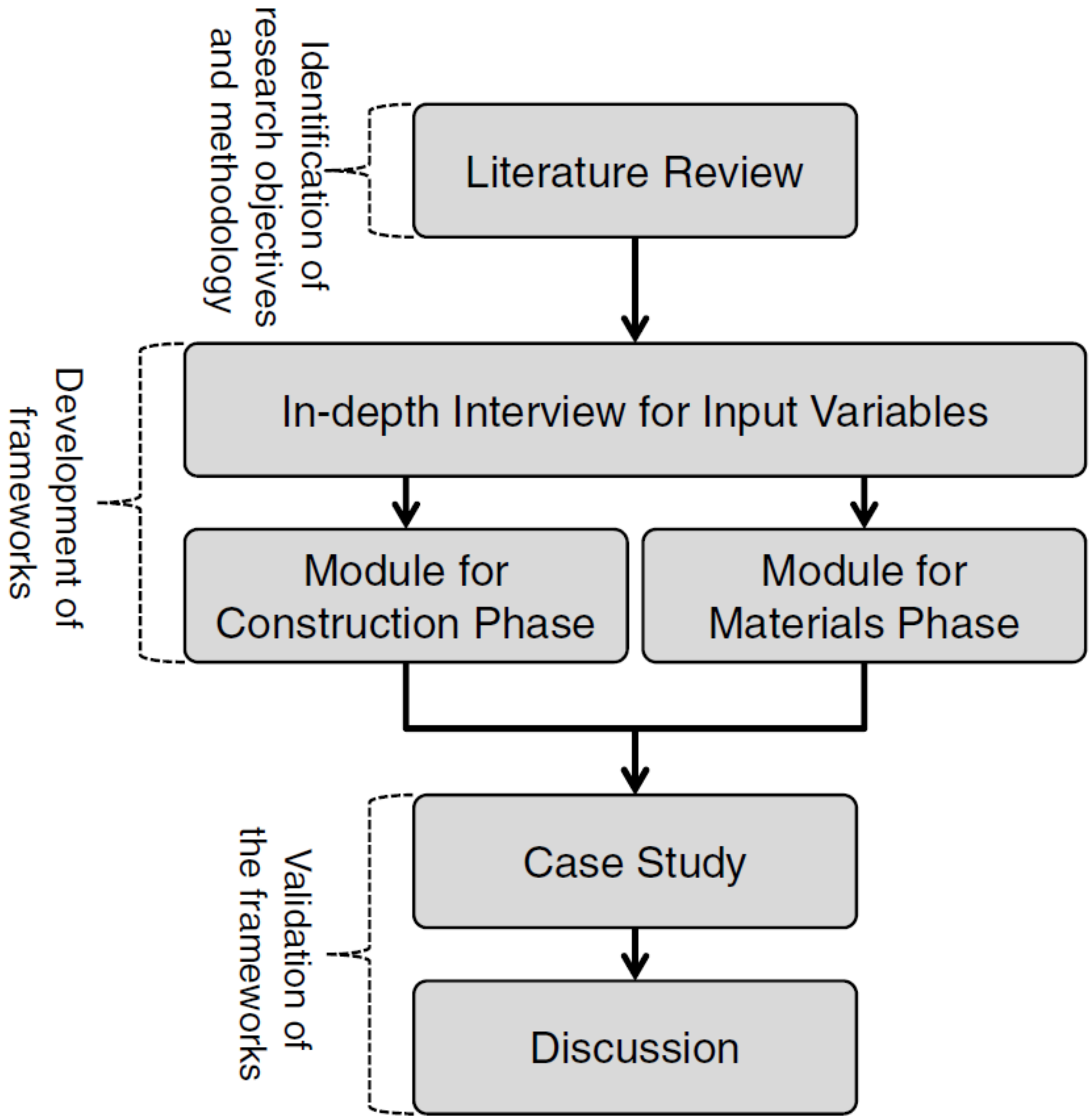
Research Needs and Objectives

- Relatively little attention has been paid to estimating GHG emissions from civil engineering structures, such as pavement.
- A possible reason is a lack of relevant information in the early phase of civil engineering projects.
- The lack of available information, coupled with the need to understand the GHG aspect, strongly demands a new method for estimating GHG emissions in the planning phase of a pavement project.
- The main objective of this study was to develop a framework for the estimation of GHG emissions caused by asphalt pavement construction during the materials (bitumen and aggregates) production and construction phases.

Sources of GHG Emissions in the scope



Overall Description of the Research Process



GHG Emissions during Construction Phase

$$\begin{aligned}\text{GHG emissions}(\text{tCO}_2\text{e}/\text{lane-km}) &= \left(\frac{\text{total work quantity}}{\text{work quantity per unit time}}\right) \\ &\times (\text{energy consumption per unit time}) \\ &\times (\text{carbon emission factor}) \qquad (1)\end{aligned}$$

Estimation Module for GHG Emissions during Construction Phase

1. Identify Input Variables for Each Project

- Identify available information and reference
  - Statement of requirements
  - Outline of a project
  - Standard specification
  - Digital map
- Calculate the input variables using commercial software

Input Variables for Input Nodes

- Volumetric data (m^3)
  - Excavation, embankment, and transportation
- Soil condition
  - Topsoil, weathered rock, and rock
- Equipment types

↓

2. Calculate GHG Emissions for Each Project

- For each equipment usage, calculate GHG emissions using Eq. (1) (tCO_2e)

Variables for Eq. (1)

- Total work quantity (m^3)
- Work quantity per unit time (m^3 /h)
- Energy consumption per unit time (L/h)
- Carbon emission factors (from IPCC)

- For the whole project, calculate GHG emissions (output node) (tCO_2e/lane-km)

→

3. Develop ANN Models

- Determine input variables for input nodes
  - Consider the model accuracy and efficiency
- Determine the model architecture
  - Consider the model accuracy and efficiency
- Prepare the projects data for training and testing sets
- Train and test the ANN model
  - If the model fails to meet an error tolerance level, the model development process is repeated until it reaches the tolerance level.

↓

4. Apply the ANN Model

- If a project of interest is similar to those used for developing the ANN model, the ANN model with its trained weights can be applied to the new project.
  - Consider geographic features along with construction practices
- Otherwise, steps 1, 2, and 3 are repeated to develop the model with sufficient accuracy and efficiency.

GHG Emissions during Material Production Phase

$$
\begin{aligned}
&\text{GHG emissions } (\text{tCO}_2\text{e/lane-km}) \\
&= 1{,}000 \times \left(\frac{\text{width}}{\text{number of lanes}}\right) \times (\text{thickness}) \\
&\quad \times (\text{loss conversion factor}) \times (\text{density of pavement material}) \\
&\quad \times (\text{emission factor}) \qquad (2)
\end{aligned}
$$

Estimation Module for GHG Emissions during Material Production Phase

1. Identify Available Information

- Identify available information and reference
  - Statement of requirements
  - Outline of a project
  - Standard specification

↓

2. Estimate GHG Emissions

- Infer the input variables from the available information
  - Pavement type: asphalt and concrete
  - Standard cross-section (m): width, surface, bind, and base layers
- Determine loss conversion factor and density of pavement material
- Calculate emission factor
- Calculate GHG emissions using Eq. (2) (tCO_2e/lane-km)

Input Variables for Eq. (2)

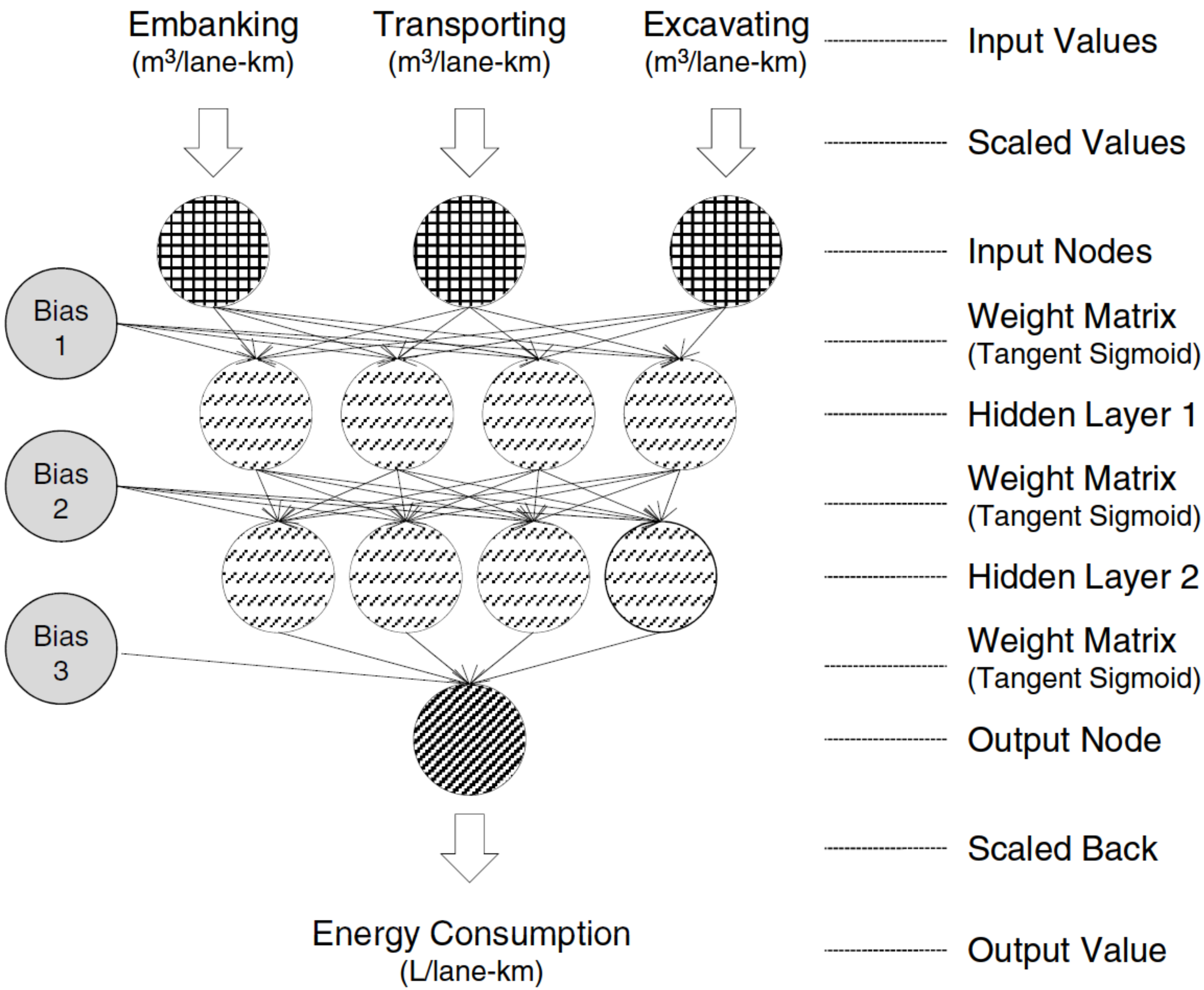
- Width (m)
- Thickness (m)
- Loss conversion factor (%)
- Density of pavement material (t/m^3)
- Emission factor (tCO_2e/t)

↓

3. Apply the Estimates

- If the information is available on the project scale, calculate and use the estimate for the whole project.
- If more accurate geometric and material information is available, calculate and use the estimate for each corresponding line or section.

The Neural Network Model



Conclusions

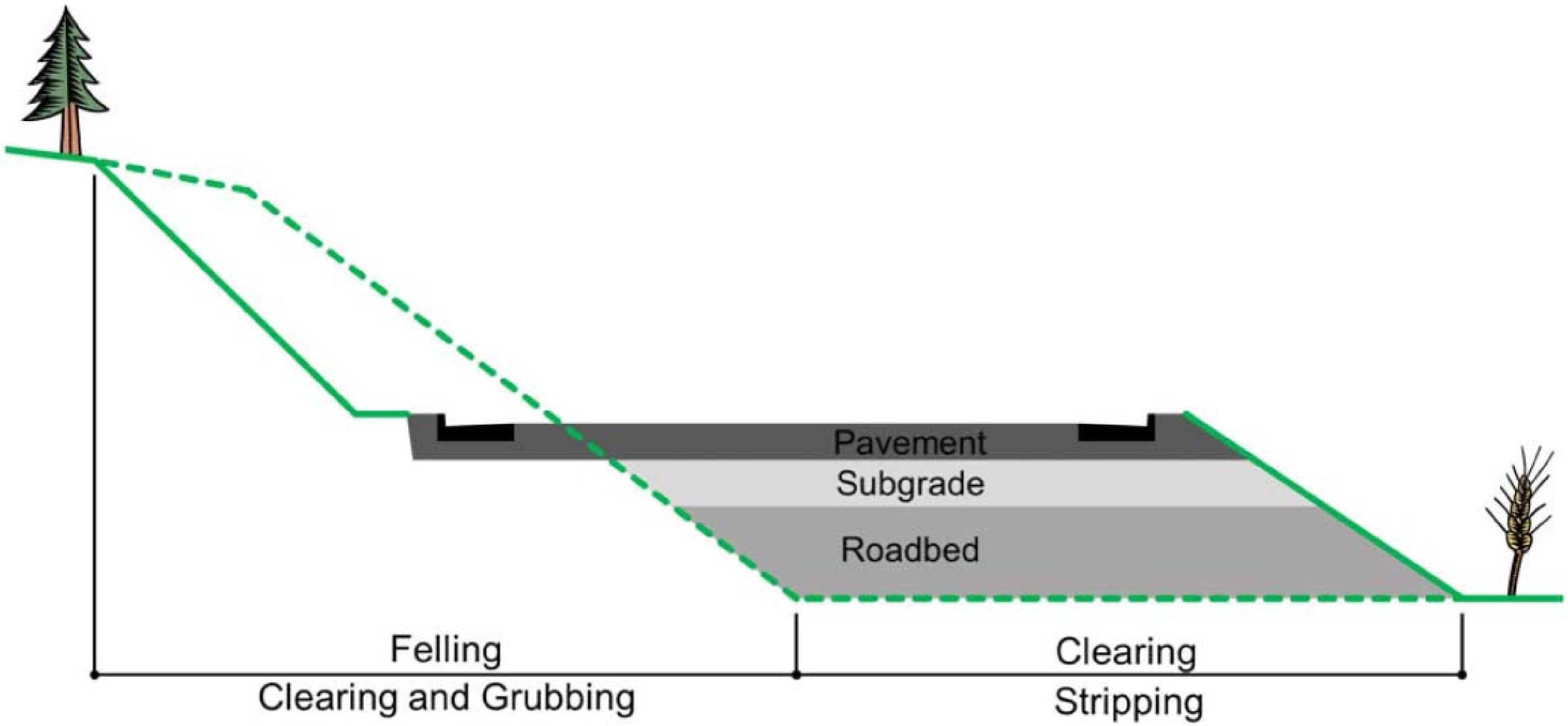
- This study proposed a framework for estimating GHG emissions associated with asphalt pavement construction projects.
- GHG emission from earthwork was modeled by an artificial neural network, due to its nonlinear characteristics. Materials production GHG emissions were modeled by a parametric method, due to the geometric nature of the process.
- When applied to actual asphalt pavement projects, the neural network model coupled with the parametric model produced only a −11.2% error rate in estimating GHG emissions.

Estimation of Greenhouse Gas Emissions from Land-Use Changes Due to Road Construction in the Republic of Korea

Research Needs and Objectives

- Land-use changes are one of the three major sources of greenhouse gas (GHG) emissions due to human activity, along with fossil fuel combustion and cement production.
- Because road construction is the foremost cause of land-use changes, it is crucial to quantify the GHG emissions from road construction.
- However, the effect of GHG emissions attributed to land-use change for a single road construction project has not yet been fully investigated.
- The main objectives of this study were to quantify the amount of GHG emissions caused by land-use changes from road construction and to provide mitigation methods for such emissions.

Conceptual Cross-Sectional View of a Road



Change in Carbon Stocks

$$\Delta C = (A_{\text{after}} \times C_{\text{after}}) - (A_{\text{before}} \times C_{\text{before}}) \quad (1)$$

where ΔC = change in carbon stock attributed to the conversion of land to roads, [tons of carbon (tC)]; A_{after} = area of land for revegetation (ha); C_{after} = carbon stocks in revegetation area (tC/ha); A_{before} = area of road construction (i.e., area of felling and stripping in Fig. 1) (ha); and C_{before} = carbon stocks in land immediately before conversion to road (tC/ha). In this study, the term "revegetation" is defined in a broad sense to include even the vegetation on an originally nonvegetated area; that is, revegetation means all the vegetation works that are executed as part of the road construction.

Biomass Carbon Stock Associated with Forestland

The biomass carbon stock associated with forestland can be obtained by Eq. (2):

$$C_{\text{before}} = V \times \text{WD} \times \text{BEF} \times R \times \text{CCF} \tag{2}$$

where V = unit volume of merchantable growing stock (m^3/ha); WD = basic wood density (t/m^3); BEF = biomass expansion factor for the expansion of merchantable stock biomass to aboveground biomass (%); R = root-shoot ratio (%); and CCF = carbon conversion factor (%).

Estimation Framework for Determining net GHG emissions from land-use change due to road construction

1. Identify the Land Area to be Converted (A_{before})

- Identify the land areas to be converted to road
  - Forestland
  - Other land (cropland, grassland, and wetlands)
- If design documents are fully developed, consult the area information in the bill of quantity
  - Forestland=the area of felling (or clearing and grubbing)
  - Other land=the area of stripping (or clearing)

2. Calculate the Unit Carbon Emissions (C_{before})

- Identify the available data to calculate C_{before} according to land type
- For each land type and ecosystem component (biomass, dead organic matter, and soils), determine a method
  - Select Tier 3 method if advanced methods based on detailed country-specific data exist
  - Select Tier 2 method if the input variables for Eq. (2) are available

Input Variables for Eq. (2)

- *V*: unit volume of merchantable growing stock (m^3/ha)
- *WD*: basic wood density (t/m^3)
- *BEF*: the biomass expansion factor for the expansion of merchantable stock biomass to above-ground biomass (%)
- *R*: the root-shoot ratio (%)
- *CCF*: the carbon conversion factor (%)

  - Select Tier 1 method if only the default data (from the IPCC) are available
- Calculate the unit GHG emissions using the selected method

3. Identify the Revegetable Land Area (A_{after})

- Identify the revegetable area of the road
  - Consider tunnel and bridge sections as nonrevegetable
  - Consider other defunctionalized area of carbon pool capability such as interfaces between different sections

4. Calculate the Unit Carbon Sequestration (C_{after})

- Identify possible alternatives for sequestrating carbon
  - Turfing, planting, etc.
- Select the techniques for green area management
  - Consider the carbon sequestration capability as well as road safety concerns
  - Consider active growing period
- Calculate the unit carbon sequestration
- Additionally, apply global warming potential (GWP) reduction methods
  - Consider the GWP reduction capability as well as road safety concerns
  - Consider their economic and engineering feasibility

Possible GWP reduction methods

- Material reuse and recycle (tC/lane-km)
  - Merchantable growing stock (14)
  - Topsoil (2)

5. Estimate the net GHG emissions

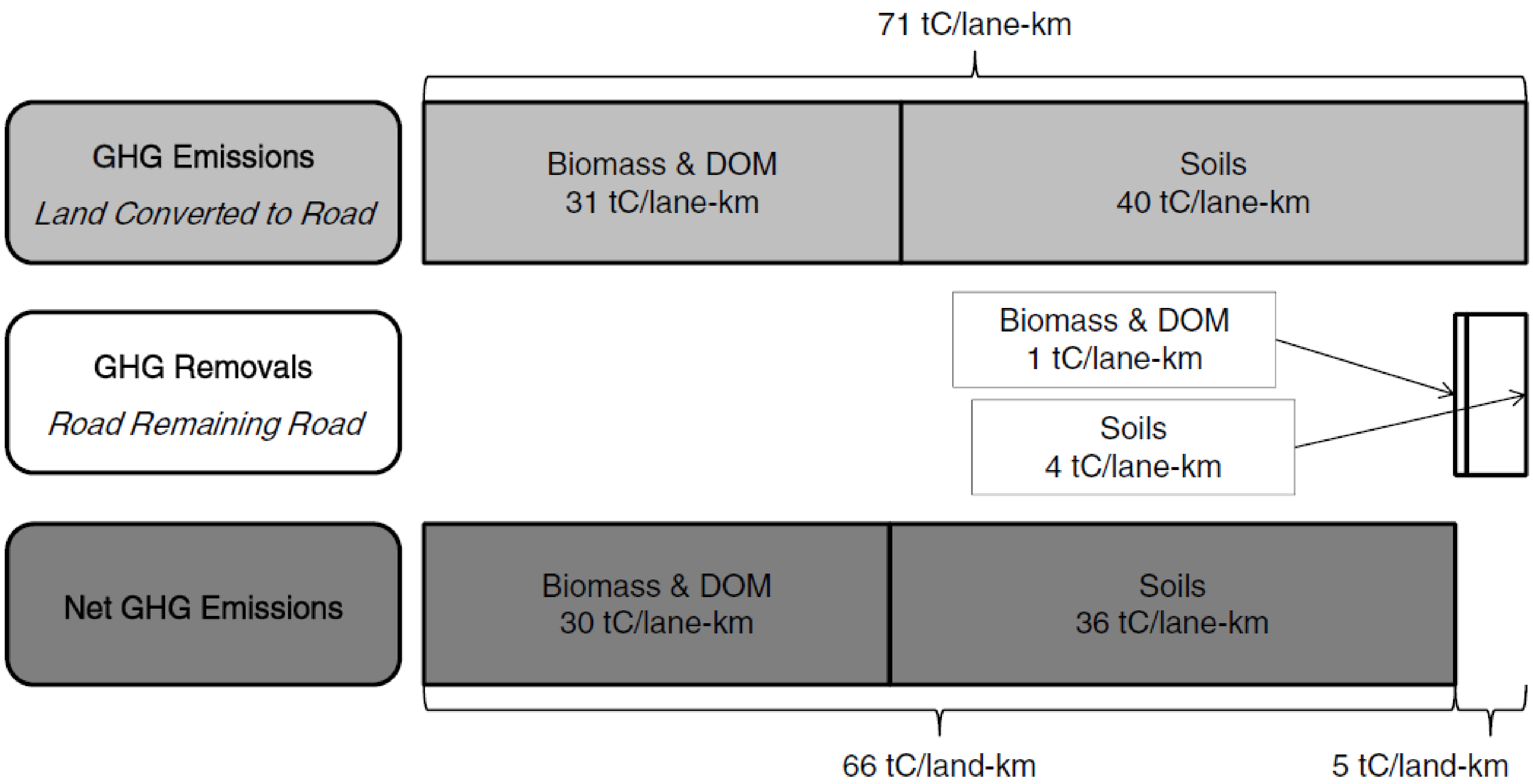
- Calculate the change in carbon stock (ΔC) using Eq. (1)

Eq. (1)

$$\Delta C = (A_{after} \times C_{after}) - (A_{before} \times C_{before})$$

- For comparison purpose, divide the GHG emissions by the number of lanes and the total length of the road

GHG emissions and removal caused by land-use changes due to road construction



Global Warming Reduction Potential by Approach

Table 5. Global Warming Reduction Potential by Approach

Category	Approach	Global warming reduction potential (tC/lane–km)
Biological carbon sequestration	Turfing	5
	Planting	20
Material reuse and recycle	Merchantable growing stock	14
	Topsoil	2

Conclusions

- Following the IPCC method, a framework was developed in this study to estimate GHG fluxes from land-use change caused by road construction.
- The framework makes it possible to obtain the most reasonable and sound estimate of the net GHG emissions based on the available data with different levels of detail.
- Eighteen road construction cases in the ROK, along with national standard references, the IPCC Guideline (2006), and other previous study results, were used to validate the framework.