

# An Inventory Analysis for Estimating CO<sub>2</sub> Emission in End-of-Life of Single or Independent Building

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**Abstract.** In this study, an inventory analysis was conducted to estimate the CO<sub>2</sub> emissions in End-of-Life (EOL) of single and independent buildings (SIB). For this purpose, EOL were subdivided into the dismantling stage, the waste transportation stage and the waste disposal stage. And the CO<sub>2</sub> emissions estimation formula based on the analysis of factors influencing on CO<sub>2</sub> emissions was suggested in this study. In order to build the Life Cycle Inventory (LCI) DB required to draw the CO<sub>2</sub> emissions estimation formula, the energy consumption of dismantling equipment and transport vehicles used at EOL was analyzed based on the existing literatures and data to build the CO<sub>2</sub> emissions data, and the CO<sub>2</sub> emission coefficients were drawn by processing method and by type of demolition waste.

## 1 Introduction

Global warming issues and environmental problems are the global common concerns. Especially, the energy consumption and greenhouse gas generated by the construction activities and the buildings are the subjects of interest among many researchers. Various researches have been conducted on CO<sub>2</sub> emissions energy consumption of apartment houses throughout the lifecycle. Many studies have been conducted on CO<sub>2</sub> emissions and energy consumption at various stages of the building lifecycle, including production of construction materials, construction of buildings, and use and maintenance of the building. It is true, however, that there has been considerable less studies on EOL of SIB when compared with the studies on apartment houses.

The construction activities in the countries like Korea where the land area is restricted, it is inevitable to dismantle existing SIN to secure land for new construction activities. In order to estimate the CO<sub>2</sub> emissions in EOL of SIB, this study performed the inventory analysis on transportation and handling of demolition waste generated from the dismantling activities and the dismantled structures.

## 2 Methodology

EOL is subdivided into the dismantling stage, the loading and transportation of demolition waste stage, and the waste disposal stage. In this study, an inventory analysis was performed to estimate the energy consumption and CO<sub>2</sub> emissions at each of the 3 stages above.

### 2.1 Demolition phase

The dismantling stage is composed of the dismantling work using the equipment, the water spraying work to prevent scattering of dust and pollutant, and the

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This research is modification and supplementation to doctorate thesis "A Study on the Prediction of CO<sub>2</sub> Emissions and Cost in End-Life of Residential Building."

demolition waste sorting and soil collecting work. The CO<sub>2</sub> emissions in the dismantling stage can be estimated based on the energy consumption of the equipment used for each work and the source of energy. The energy consumption at the dismantling stage can be estimated with equation 1, and the CO<sub>2</sub> consumption with E equation 2 in consideration of the energy consumption and the CO<sub>2</sub> emissions coefficient of the energy source.

$$E.C_{DP} = \sum DWG * (E_{DE} + E_{WE} + E_{SE}) \quad (1)$$

$$CO_2 \text{ Emission}_{DP} = E.C_{DP} * CO_2 \text{ emission coefficient} \quad (2)$$

In equation 1 and 2, E.C<sub>DP</sub> indicates the energy consumption (L) at the dismantling stage; DWG is the estimated amount of the demolition waste (m<sup>3</sup>); E<sub>DE</sub> (L/m<sup>3</sup>) is the energy consumption of the dismantling equipment; E<sub>WE</sub> (L/m<sup>3</sup>) is the energy consumption of the water spraying equipment; E<sub>SE</sub> (L/m<sup>3</sup>) is the energy consumption during sorting of demolition waste and collection of soil; CO<sub>2</sub> Emission<sub>DP</sub> (kg-CO<sub>2</sub>) is the CO<sub>2</sub> emissions at the dismantling stage. The main energy source used by the dismantling equipment is diesel. The national LCI DB [8] of Korea applies the per litter CO<sub>2</sub> emission coefficient of 2.59E+00 kg-CO<sub>2</sub>/L for diesel.

### 2.2 Waste transportation phase

The CO<sub>2</sub> emission in the transportation stage is occurred by consumption of energy of the demolition waste transport vehicles. There are a few considerations in estimating the energy consumption of the transport vehicles.

Firstly, it is required to consider the types of transport vehicle, the number of vehicles required, and the distance of transportation. Fuel efficiency of empty vehicles and loaded vehicles also needs to be considered in estimating the energy consumption.

Secondly, loading of demolition waste on the vehicle generates the sponge effect, increasing the volume of waste. Therefore, the change of volume of the demolition waste must be allowed for in estimating the number of transport vehicles. When considering the variable of change of waste volume and the above-mentioned factors,

$\text{CO}_2$  emissions at the transportation stage can be estimated with the following equation 3.

$$\text{CO}_2 \text{ Emission}_{TP} = \sum \{(DWG * \text{Vol factor}/V_L) * T.D/F.E\} * 2.59 \quad (3)$$

where,  $\text{CO}_2$  Emission  $_{TP}$  is the  $\text{CO}_2$  emissions ( $\text{kg-CO}_2$ ) at the transportation stage; Vol factor is the change of volume of demolition waste;  $V_L$  is the loadage ( $\text{m}^3$ ) of the transport vehicle; T.D is the transportation distance (km); and F.E is the fuel efficiency (km/L) of the transport vehicle.

### 2.3 Waste disposal phase

For the  $\text{CO}_2$  emissions at the waste disposal stage, it is required to consider the amount of demolition waste generated and the disposal methods depending on the type of waste.  $\text{CO}_2$  emissions from burial, burning and recycling of waste must be considered for different types of waste.  $\text{CO}_2$  emissions by type of waste can be estimated with the following equation 4.

$$\text{CO}_2 \text{ Emission}_{DP} = \sum DWG * \text{CO}_2 \text{ Factor} \quad (4)$$

Where,  $\text{CO}_2$  Emission  $_{DP}$  is  $\text{CO}_2$  emissions ( $\text{kg-CO}_2$ ) at the disposal stage of demolition waste;  $\text{CO}_2$  factor is the  $\text{CO}_2$  emission coefficient for different waste disposal methods.

## 3 Inventory analysis and results

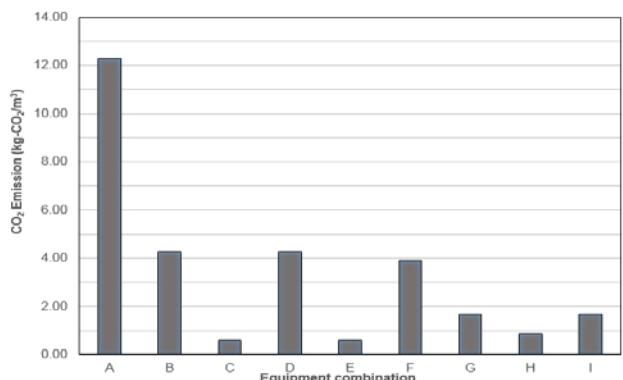
$\text{CO}_2$  emissions can be estimated with the equation 1, 3 and 4 as mentioned in the methodology of study. It is required to perform inventory analysis for energy consumption and  $\text{CO}_2$  emissions of the equipment used in the structure dismantling stage, the waste transportation stage and the waste disposal stage as mentioned in this study. In this study, the inventory analysis for  $\text{CO}_2$  emissions was conducted based on the energy consumption analysis of the existing literatures and reports.

### 3.1. Demolition phase

To estimate the  $\text{CO}_2$  emissions of the equipment used in the dismantling stage, the Standard Estimating System for Construction in Korea [1] and the existing literatures [2], [3] and [4] were used. Table 1 summarizes the work load and the energy consumption of the dismantling equipment.

**Table 1.** The per-hour workload and fuel consumption of the equipment used for dismantling

Stage	Name	Combination of equipment	Basic assumption	Work load ( $\text{m}^3/\text{h}$ )	Fuel consumption ( $\text{L}/\text{h}$ )
Dismantling of structure	A	Backhoe (1.0 $\text{m}^3$ )+ Giant Breaker (0.7 $\text{m}^3$ )	Reinforced concrete with the thickness of less than 30cm	2.45	11.6
	B	Backhoe (1.0 $\text{m}^3$ ) + Crusher (2@137ton)	Reinforced concrete	11.8	19.5
	C	Backhoe (1.0 $\text{m}^3$ )	Block, brick	76.4	17.7
	D	Backhoe (1.0 $\text{m}^3$ )+ Crusher (2@137ton)	Block, brick	11.8	19.5
	E	Backhoe (1.0 $\text{m}^3$ )	Wooden structure	76.4	17.7
Sorting and collection of soil	F	Sprinkler vehicle	Others	6.75	10.2
	G	Backhoe (1.0 $\text{m}^3$ )	Concrete	27.5	17.7
	H	Backhoe (1.0 $\text{m}^3$ )	Mixed waste	52.08	17.7
	I	Backhoe (1.0 $\text{m}^3$ )	Brick, block	27.5	17.7



**Figure 1.**  $\text{CO}_2$  emissions of the equipment combination by the dismantling work load

Table 1 shows the per-hour workload and fuel consumption of the equipment used for dismantling of SIB. Figure 1 shows the result of estimation performed based on Table 1 on the CO<sub>2</sub> emissions of the equipment by the dismantling work load. Out of the combinations of dismantling equipment in Figure 1, the combination of breaker and crusher with low per-hour work load shows considerably high CO<sub>2</sub> emissions. The sprinkler vehicle used during dismantling of structures is expected to generate considerably high CO<sub>2</sub> emissions.

### 3.2 Waste transportation phase

In estimating the energy consumption at the transportation stage, the Standard Estimating System for Construction in Korea [1] was used to find the fuel efficiency of vehicles used in transportation of waste (see Table 2). Change of volume during loading of waste was considered based on the existing literatures [5] and [6] (see Table 3)

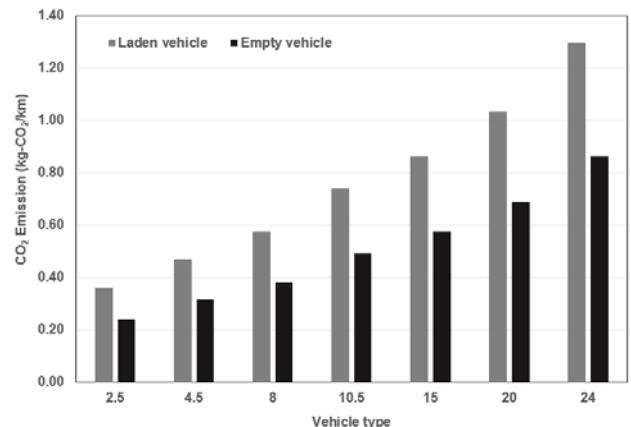
**Table 2.** The fuel efficiency of vehicles used in transportation of waste

Classification	One-time loadage by type of transport vehicle (m <sup>3</sup> )	Fuel efficiency (km/L)	
		Loaded	Empty load
Vehicle type	2.5	1.52	7.2
	4.5	2.73	5.5
	8	4.86	4.5
	10.5	6.39	3.5
	15	9.13	3
	20	12.17	2.5
	24	14.6	2

Figure 2 shows the result of CO<sub>2</sub> emissions estimated based on vehicle type and loading state in Table 2. In the transportation stage, a transport vehicle emit 50% more CO<sub>2</sub> when loaded than when it is empty.

**Table 3.** The change of volume of the demolition waste in transportation of waste

Classification	The change of volume
Concrete	1.1
Brick	1.25
Block	1.1
Mixed waste	1.00
Soil	1.0
Metals	1.02
Others	1.0



**Figure 2.** CO<sub>2</sub> emissions of the equipment combination by the dismantling work load

### 3.3 Waste disposal phase

CO<sub>2</sub> emissions at the waste disposal stage can be estimated with the CO<sub>2</sub> emission coefficient according to the type of waste and the disposal method. For this estimation, the CO<sub>2</sub> emission coefficient during disposal waste in the National LCI DB of Korea [8] was used, and the type of demolition waste and the disposal method were selected based on Article 42-2 of the “Construction Waste Recycling Promotion Act” of the Ministry of Environment. Table 4 shows the CO<sub>2</sub> emission coefficient for different waste disposal methods.

**Table 4.** CO<sub>2</sub> emission coefficient by disposal methods of demolition waste

Disposal methods	Name	Emission coefficient	Unit
Landfill	Timber	6.07E-02	kg-CO <sub>2</sub> /kg
	Plastic	7.98E-02	kg-CO <sub>2</sub> /kg
	Glass	7.00E-03	kg-CO <sub>2</sub> /kg
	Concrete (including brick, block, roof tile)	7.00E-03	kg-CO <sub>2</sub> /kg
	Hazardous waste	8.87E-02	kg-CO <sub>2</sub> /kg
incineration	Timber	1.17E-02	kg-CO <sub>2</sub> /kg
	Plastic	2.35E+00	kg-CO <sub>2</sub> /kg
	Designated waste	3.43E-01	kg-CO <sub>2</sub> /kg
Recycling	Timber	1.39E-02	kg-CO <sub>2</sub> /kg

	Plastic	1.86E-02	kg-CO <sub>2</sub> /kg
	Glass	9.76E-03	kg-CO <sub>2</sub> /kg
	Concrete (including brick, block, roof tile)	1.38E-02	kg-CO <sub>2</sub> /kg
	metals	3.79E-03	Kg-CO <sub>2</sub> /kg

- [7] G. W. Cha, *A Study on the Prediction of CO<sub>2</sub> Emissions and Cost in End-Life of Residential Building*, A Doctoral Dissertation, Kyungpook National University (2014)
- [8] <http://www.edp.or.kr/lci/co204.asp>

## 4 conclusion

In this study, an inventory analysis was conducted to estimate the CO<sub>2</sub> emissions in EOL of SIB in Korea. For this purpose, EOL were subdivided into the dismantling stage, the waste transportation stage and the waste disposal stage. And the CO<sub>2</sub> emissions data of equipment and the CO<sub>2</sub> emission coefficient for different types of waste were estimated. Based on the CO<sub>2</sub> emissions data built with the CO<sub>2</sub> emissions estimation formula and the inventory analysis suggested in this study, it may be possible to conduct a research on the greenhouse gas emissions and its reduction method in EOL of SIB.

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## References

- [1] *Standard of Construction Estimate*. Korea Institute of Civil Engineering and Building Technology (2013)
- [2] S.H. Kwon, K.J. Kim, B.S. Kim, S.B. Kim, *Evaluation of Environmental Economics on Dismantling Projects Using LCI DB*, Korea Journal of Construction Engineering and Management, Conference paper. 207-212 (2008)
- [3] J.S. Jung, J.S. Lee, Y.J. An, K.H. Lee, Bae, K.S. Bae, M.H. Jun, *An Analysis of Emission of Carbon Dioxide from Recycling of Waste Concrete*, Journal of the Architectural Institute of Korea, 24(10): 109-116 (2008)
- [4] *The environmental load unit composition and program development for LCA of building – the construction of method with LCA for estimating environmental building*. Korea Institute of Civil Engineering and Building Technology (2014)
- [5] C. Llatas. *A model for quantifying construction waste in projects according to the European waste list*, Waste Management, Volume 31. 1261-1276 (2011)
- [6] Jack C.P. Cheng, Lauren Y.H. Ma. *A BIM-based system for demolition and renovation waste estimation and planning*, Waste Management, Volume 33. 1539-1551 (2013)