Greenhouse Gases (GHG) Emissions during the Construction Stage of a Precast Building in Indonesia

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Abstract. Growth in the construction sector could stimulate the development of other sectors. However, the construction industry has been known as a sector that brings a great contribution to energy consumption and produces Greenhouse Gases (GHG) emissions that harm the environment. To support the implementation of sustainable infrastructure, calculating the greenhouse gas emissions produced by a construction project through its lifecycle is necessary. This study analyzes greenhouse gas emissions produced in constructing a three-story precast building. The emission source was calculated from the materials, transportation activities, and erection activities using a Life Cycle Assessment (LCA) approach. The embodied carbon data was adopted from the Inventory of Carbon and Energy (ICE) database. From the analysis that has been carried out, the precast building project generated 124,882.7 kgCO₂eq, or 283.18 kgCO₂eq GHG per m² of building. The contribution of emissions from materials, the transportation precast components, and the erection of precast components was 119,649 kgCO₂eq (95.81%), 632.41 kgCO₂eq (0.51%), and 4,599.30 kgCO₂eq (3.68%) respectively.

1. Introduction

The development of a country could be seen from its construction sector. On the other hand, the construction sector also has great potential for environmental impact. According to a report by the World Green Building Council, the building and construction sector is responsible for 39% of the total greenhouse gas emissions produced by all sectors where 28% comes from building operational emissions, and 11% comes from material emissions and building construction processes [1]. It shows that the contribution of the construction sector is quite significant in greenhouse gas emissions produced worldwide. The awareness of many countries to reduce emission levels is starting to increase. According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions should be limited to maintain the environment [2]. Every sector that produces emissions should measure greenhouse gas emissions and find methods and solutions to reduce them.

Indonesia has begun to give attention and formulate steps in dealing with greenhouse gas emissions. The government commitment can be seen from the issuance of several regulations which explains that Indonesia must reduce its greenhouse gas emissions while ensuring the people’s prosperity. The Indonesian government has identified several areas with the most significant potential to reduce greenhouse gas emissions, namely: forestry, agriculture, energy, transportation, and waste. However, greenhouse gas emissions have not been given much attention in the construction sector. For example, Law Number 32 of 2009 concerning Environmental Protection and Management explains that a construction project must minimize adverse impacts on the environment. This regulation focuses more on environmental pollution locally and ignores pollution or greenhouse gas emissions. Through the Ministry of Environment and Forestry, the government is drafting a Presidential Regulation on the
Economic Value of Carbon, which is designed to calculate greenhouse gas emissions more precisely. The proposed Presidential Regulation will encourage project owners and contractors to calculate greenhouse gas emissions from the projects they are working on.

Nevertheless, in the Indonesian construction industry, the number of research exploring the amount of greenhouse gases emission is still limited. The previous study has been explored the greenhouse gases in a toll road construction project [3] and conventional concrete building [4]. The calculation of greenhouse gases will depend on the construction method and the characteristic of the infrastructure. Research focusing on prefabrication concrete building has not been exercised yet. Thus, this research aims to analyses greenhouse gas emissions of precast and cast-in-place concrete through a life cycle assessment approach. By conducting this research, it is expected that the calculation of greenhouse gases in a precast concrete building could be done and enrich the existing body of knowledge on greenhouse gases emissions calculation in the construction projects in Indonesia.

2. Materials and Methods

In this study, LCA was implemented to calculate the carbon emissions of precast and cast-in-place concrete. LCA is a widely used method of evaluating the environmental performance of the entire product life cycle. According to ISO 14040 [5], LCA research consists of four interactive phases, namely (i) definition of objective and scope, (ii) life cycle inventory, (iii) impact assessment, and (iv) interpretation. The first stage determines the critical elements in the LCA investigation, such as the objectives of the investigation, the boundaries of the system, and the target audiences. The second stage is to collect primary data, establishes an LCA model, and calculates the inventory results. Next, use a specific impact assessment method to analyze the list further and get the index results of the researched impact category. The final stage involves interpreting the results according to the definition of goals and scope and performing advanced analysis to detect emission hot spots.

2.1 Scope of the study

2.1.1 Greenhouse gas emission. According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, greenhouse gases include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFC), Ozone (O₃), Hydrofluorocarbon (HFC), Perfluorocarbon (PFC) and Sulfur Hexafluoride (SF₆) [2]. Greenhouse gases are mainly composed of CO₂, CH₄, and N₂O, and the remaining part is rarely emitted in this process [6]. Different greenhouse gases have different effects on the environment. Global warming potential (GWP) values are generally used to illustrate the impact of different gases on the climate. CO₂ is generally used as the reference standard for the GHG effect. By multiplying the emission factor of a single gas by the corresponding GWP of that gas, the emissions of other greenhouse gases (such as CH₄, N₂O, and CO) are converted into so-called CO₂ equivalents. The GWP values of CO₂, CH₄, and N₂O in the 100-year time frame are shown in Table 1. Therefore, the GHG emission factor (as CO₂ equivalent) can be calculated using Equation 1.

\[
\text{GHG Emission Factor} = \sum_{c=1}^{C} F_c \times \text{GWPV}_c
\]

(1)

Where Fc is a given gas c emissions factor per unit, and GWPVc is the GWP value of gas c.

| Industrial designation or common name | Chemical formula | GWP values for a 100-year time horizon |
|--------------------------------------|----------------|---------------------------------------|
|                                      |                | Second Assessment | Fourth Assessment | Fifth Assessment |
|                                      |                | Report (SAR)      | Report (AR4)      | Report (AR5)     |
| Carbon dioxide                       | CO₂            | 1                  | 1                  | 1                |
| Methane                              | CH₄            | 21                 | 25                 | 28               |
| Nitrous oxide                        | N₂O            | 310                | 298                | 265              |
2.1.2 Calculation boundaries. The goal of the research is to investigate the carbon emission of precast and cast-in-situ construction methods. An educational building project in Yogyakarta is studied. The building is three floors building in a site area of 147 m² with a length of 21 meters and a width of 7 meters. Structural work such as foundation work, tie beams, columns, beams, floor plates, and stairs was the primary object of this study. This study reviewed the embodied carbon in precast concrete, cast-in-situ concrete, and reinforced steel.

2.1.3 Sources of greenhouse gas emission. This study's calculation of greenhouse gas emissions was carried out on off-site prefabrication for building precast components and on-site construction for in situ cast and assembly. The GHG Protocol distinguishes greenhouse gas emissions by source into two, namely direct and indirect emissions. Direct greenhouse gas emissions are emissions from sources owned or controlled by the reporting entity. Indirect greenhouse gas emissions are emissions generated by the activities of the reporting entity but from sources owned or controlled by another entity [7]. The four emission sources considered in this study are shown in Table 2.

| Table 2. Greenhouse gas emission sources |
|------------------------------------------|
| Emission Source                  | Emission Type | Definition                                             | Reviewed in this study? |
| Construction Materials            | Indirect      | GHG emission from precast and cast-in-place concrete and reinforcement | Yes                    |
| Material Transportation           | Direct        | GHG emission from material transportation              | Yes                    |
| Waste Material Transportation     | Direct        | Transportation of precast components from the factory to the project site | Yes                    |
| Precast Component Transportation  | Direct        | Precast component erection activity                     | Yes                    |
| Use of Heavy Equipment / Oil      | Direct        | -                                                       | No                     |
| Water and Waste Treatment         | Indirect      | -                                                       | No                     |

Regarding the inclusion of life cycle stages, there are two types of LCA: full LCA and partial LCA. Full LCA refers to those LCA studies that consider all stages of the product life cycle (i.e., cradle to grave). On the other hand, some LCAs only consider one or more stages, such as gate to gate, cradle to gate, and cradle to site. This study is a partial LCA, which includes the life cycle "cradle to site" phase.

2.2 Life cycle inventory

2.2.1 Collection of data. Data collection is a critical step in LCA modelling. Although the ideal LCA should be based entirely on site-specific data, obtaining such data from stakeholders requires a lot of time and effort. The popularity of LCA is mainly due to its effectiveness in using sophisticated databases. In LCA research, the combination of site-specific data and existing databases is usually unavoidable. This study used those two types of data.

Various methods are used to collect site-specific data. As-built drawings, precast concrete factory location, type of vehicles and heavy equipment used, and erection duration of precast components are obtained from the contractor. Vehicle and heavy equipment specification data were obtained from the manufacturers. Meanwhile, the data of embodied carbon which is the amount of carbon produced in the production process of building material was taken from The Inventory of Carbon and Energy (ICE) book by BSRIA [8]. This book calculates embodied carbon material resulting from the combustion emissions of fuels used to manufacture the material, including during mining, transportation processes, and the production process of these materials and emissions resulting from non-combustion processes such as chemical reaction processes. The emissions were calculated from raw material mining (cradle) until the material is ready to use and transported outside the factory (gate).
The value of cast-in-situ concrete embodied carbon in the ICE book is assumed to use ready mix concrete from cradle to factory stage. The value of embodied carbon in precast concrete covers the calculation of the emissions resulting from the manufacture of precast concrete starting from the taking of raw material (cradle), the process of transporting materials to the factory, and plant operations. The precast is assumed to be 38 km for aggregate, 100 km for cement material. Meanwhile, the value of embodied carbon reinforcement was calculated from the emissions generated by the manufacturing process of reinforcing steel starting from the taking of raw material (cradle), the process of transporting the material to the manufacturing plant, reinforcing steel, as well as the process of making reinforcing steel in the factory until it is ready to be distributed to the project site. The steel was assumed as UK typical with 59% of recycled content. Embodied carbon values used in this study are shown in Table 3.

### Table 3. Embodied carbon of materials [8]

| Material                     | Embodied Carbon (kgCO2/kg) | Embodied Carbon (GHG) (kgCO2eq/kg) |
|------------------------------|-----------------------------|------------------------------------|
| Cast-in-place Concrete (28/35 MPa) | 0.112                       | 0.12                               |
| Precast Concrete (28/35 MPa)  | 0.139                       | 0.149                              |
| Reinforcement / Steel        | 1.31                        | 1.4                                |

The amount of greenhouse gas emissions resulting from burning fossil fuels depends on the amount and type of fuel burned. The amount of fuel is represented as activity data, while emission factors represent the type of fuel. The general equation used to estimate greenhouse gas emissions from fuel combustion can be seen in Equation 2.

\[
\text{Greenhouse gas emissions} \left( \frac{kg}{year} \right) = \text{Energy consumption} \left( \frac{TJ}{year} \right) \times \text{Emission factor} \left( \frac{kg}{TJ} \right)
\]  

(2)

According to the IPCC default, the emission factor is expressed in units of emission per unit of energy consumed (kg GHG/TJ). On the other hand, the available energy consumption data is generally in physical units (tonnes of coal, kilolitres of diesel oil, etc.). Therefore, before using Equation 2, the energy consumption data must first be converted into energy units TJ (Terra Joule) with Equation 3.

\[
\text{Energy consumption (TJ)} = \text{Energy consumption (physical unit)} \times \text{Calorific value} \left( \frac{TJ}{\text{physical unit}} \right)
\]  

(3)

The various types of fuel used in Indonesia and the calorific value of each fuel are shown in Table 4.

### Table 4. The calorific value of Indonesian fuel

| Fuel                     | Calorific Value          |
|--------------------------|--------------------------|
| Gasoline                 | 33x10^{-6}TJ/liters      |
| Diesel Fuel              | 36x10^{-6}TJ/liters      |
| Natural Gas              | 1.055x10^{-6}TJ/SCF      |
|                           | 38.5x10^{-6}TJ/Nm3       |
| Liquid Petroleum Gas     | 47.3x10^{-6}TJ/kg        |
| Coal                     | 18.9x10^{-6}TJ/ton       |

After energy consumption is calculated, the value of greenhouse gas emissions can be obtained by multiplying energy consumption by the greenhouse gas emission factor shown Table 5.

### Table 5. Greenhouse gas emission factor for stationary and mobile combustion

| Fuel Type    | EF Default IPCC 2006 Stationary Combustion, kg/TJ | EF Default IPCC 2006 Mobile Combustion, kg/TJ |
|--------------|-------------------------------------------------|-----------------------------------------------|
|              | CO₂     | CH₄    | N₂O   | CO₂    | CH₄    | N₂O   |
| Natural Gas  | 56.100  | 1      | 0.1   | 56.100 | 92     | 3     |
| Gasoline     | -       | -      | -     | 69.300 | 33     | 3,2   |
| Diesel Fuel  | 74.100  | 3      | 0.6   | 74.100 | 3,9    | 3,9   |
| Coal         | 96.100  | 10     | 1,5   | -      | -      | -     |
3. Results and Discussion

3.1 Emission from material

Precast concrete components in this building include precast columns, precast beams, and precast floor slabs. Cast-in-place concrete is used for columns, beams, tie beams, floor slabs, stairs, grouting, and foundations. The recapitulation of the calculation results for the total weight of the material used and embodied carbon from concrete and reinforcement materials can be seen in Table 6.

### Table 6. Embodied carbon of material

| Material                        | Total Weight of Material | Embodied Carbon (GHG) (kgCO₂eq/kg) | Embodied Carbon Total (kgCO₂eq) |
|---------------------------------|--------------------------|------------------------------------|---------------------------------|
| Precast concrete                | 257.523,2 m³             | 0,149                              | 38.370,95                       |
| Cast-in-place concrete          | 159.909,4 m³             | 0,12                               | 19.863,15                       |
| Precast concrete reinforcement  | 30.078,79 kg             | 1,4                                | 42.110,3                        |
| Cast-in-place concrete reinforcement | 13.788,99 kg         | 1,4                                | 19.304,6                        |
| **Total**                       |                          |                                    | **119.649**                      |

3.2 Emission from transportation activity (mobile combustion)

This study's calculation of emissions on transportation reviews the transportation activities of precast concrete elements. The route covers a distance of 9.4 km from the factory to the project site and 9.7 km from the project site to the factory. Delivery of precast components uses two different types of transportation equipment, namely trucks and loader crane trucks. The trucks were used to transport precast beam components and precast columns, while loader crane trucks were used to transport precast floor slab components. This study calculates fuel oil consumption for vehicles using Equation 4, referring to the Guidelines for Calculating Vehicle Operating Costs Part I: Running Costs [9].

\[
K_{BBM_i} = \left( \frac{\alpha + \beta_1 \frac{V_R}{V_R} + \beta_2 V_R^2 + \beta_3 R_R + \beta_4 F_R + \beta_5 F_R^2 + \beta_6 6 \times DT_R + \beta_7 A_R + \beta_8 S_A + \beta_9 B_K + \beta_{10} B_K \times A_R + \beta_{11} B_K \times S_A}{1000} \right)
\]  

(4)

Where:
- \(K_{BBM_i}\) = Consumption of fuel oil for vehicle type i, in liters/km
- \(\alpha\) = Constant (Table 7)
- \(\beta_1 \ldots \beta_{11}\) = Parameter coefficients (Table 7)
- \(V_R\) = Average speed
- \(R_R\) = Average incline
- \(F_R\) = Average derivative
- \(DT_R\) = Average degree of bend
- \(A_R\) = Average acceleration
- \(S_A\) = Standard deviation of acceleration
- \(B_K\) = Vehicle Weight

### Table 7. Constant values and parameter coefficients of the fuel consumption model [9]

| Vehicle Type | \(\alpha\) | \(1/V_R\) | \(V_R^2\) | \(R_R\) | \(F_R\) | \(F_R^2\) | \(DT_R\) | \(A_R\) | \(S_A\) | \(B_K\) | \(B_K \times A_R\) | \(B_K \times S_A\) |
|--------------|----------|-----------|----------|--------|--------|----------|---------|--------|--------|--------|-----------------|-----------------|
| Heavy Truck  | 190,3    | 3829,7    | 0,0196   | 14,536 | 7,225  | -        | -       | -      | -      | -      | 11,41           | 10,92           |

Both trucks are in the heavy truck category. To calculate heavy truck fuel consumption, coefficients of \(V_R\), \(R_R\), \(F_R\), \(B_K\), \(A_R\), and \(S_A\) are needed. The \(V_R\) value (average speed) of Heavy Trucks is 40 km/hour.
The $R_R$ (average incline) value is 2.5 and the $F_R$ (average descent) is -2.5 for flat terrain conditions which can be seen in Table 8 [9].

**Table 8. Recommended vertical alignment on various road terrain**

| Terrain Condition | Average Incline (m/km) | Average Descent (m/km) |
|-------------------|------------------------|------------------------|
| Flat              | 2.5                    | -2.5                   |
| Hill              | 12.5                   | -12.5                  |
| Mountains         | 22.5                   | -22.5                  |

The $A_R$ (Average Acceleration) value is calculated by Equation 5 [9].

$$A_R = 0.0128 \times \frac{V}{C}$$  \hspace{1cm} (5)

Where:
- $A_R$ = Average acceleration
- $V$ = Traffic volume (pcu/hour)
- $C$ = Road capacity (pcu/hour)

Traffic volume values are taken from traffic volume data and road capacity on Kaliurang road, traffic volume 1,707 pcu/hour and road capacity 6,365 pcu/hour [11]. So that the $A_R$ value is obtained at 0.0034.

The value of SA (standard deviation of acceleration) is calculated by Equation 6 [9].

$$SA = S_{A\max} \left( \frac{1.04}{1 + e^{(a_0 + a_1)/V/C}} \right)$$  \hspace{1cm} (6)

Where:
- $SA$ = Standard deviation of acceleration (m/s²)
- $S_{A\max}$ = Standard deviation of maximum acceleration (m/s²) (typical/default = 0.75)
- $a_0$, $a_1$ = parameter coefficient (typical/default $a_0 = 5.140$; $a_1 = -8.264$)
- $V$ = traffic volume (pcu/hour)
- $C$ = road capacity (pcu/hour)

$S_{A\max}$, $a_0$, and $a_1$ values are used as typical values. Values of $V$ and $C$ are taken from data on traffic volume and road capacity on Kaliurang road, traffic volume 1,707 pcu/hour and road capacity 6,365 pcu/hour [11]. Thus, the value of SA is obtained at 0.544 m/s².

The value of BK (vehicle weight) is calculated by the weight of the empty vehicle plus the weight of the load. The empty weight for the truck is 6,490 kg while the empty weight for the loader crane truck is 8,000 kg. The fuel usage will be varied and calculated using Equation 4. The total fuel consumption of each vehicle shown in Table 9.

**Table 9. Truck fuel consumption**

| No. | Type of Vehicle | Total Fuel Consumption (liter) |
|-----|-----------------|--------------------------------|
| 1   | Truck           | 95.97                          |
| 2   | Loader crane    | 137.5                          |
|     | Total           | 233.47                         |

Then the use of energy in transportation activity can be calculated using Equation 3, which is multiplying the volume of fuel consumption (liters) with the calorific value of diesel (Table 4). Thus, the energy use in transportation activity (mobile combustion) is 0.008405 TJ.

### 3.3 Emission from erection activity (stationary combustion)

Emissions calculations on erection in this study review the erection work of precast concrete components using the Tadano TR-350M rough terrain crane. The Tadano TR-350M uses a Mitsubishi 6D24-TC
engine with a power of 228 kW (kilowatt), or the equivalent of 305.75 horsepower. The fuel calculation on this crane refers to the Construction Methods and Management Book – Seventh Edition [12]. Calculation of fuel use on heavy equipment calculated using Equation 7.

\[\text{Estimated consumption} = \text{Fuel Consumption Factor} \times \text{Rated Power (hp)} \quad (7)\]

The value of the fuel consumption factor can be seen in Table 10.

**Table 10. Fuel consumption factors (gal/h/hp) [12]**

| Type of Equipment | Load Conditions | Low     | Average | High    |
|-------------------|-----------------|---------|---------|---------|
| Crane             |                 | 0.018   | 0.024   | 0.03    |

Based on Equation 7, the fuel consumption of the crane was 5.5035 gal/h or 20.833 liters/hour for low load conditions, 7.338 gal/h or 27.77 liters/hour for average load conditions, and 9, 1725 gal/h or 34,722 liters/hour for severe load conditions. The floor slab components weigh in the range of 0.304-0.842 tons, the beam components weigh between 0.888-3.12 tons, and the column components weigh between 1.608-2.304 tons. Referring to the total rated loads of the rough terrain crane specification TR-350M, the floor slabs can be categorized under low load conditions, while beams and columns can be categorized under average load conditions.

Data on the duration of crane use was obtained through interviews with the project manager. Beside the erection duration, there is a time lag between the installation of precast components, which was 5-10 minutes to remove and install precast components on the crane hook. The average calculation of the duration can be seen in Table 11, and the calculation of fuel use can be seen in Table 12.

**Table 11. Precast component erection duration**

| Component | Erection Duration (minute) | Duration Between Erections (minute) | Total Duration (minute) | Total Duration (hour) |
|-----------|---------------------------|-----------------------------------|-------------------------|-----------------------|
| Column    | 12.5                      | 7.5                               | 20                      | 0.33                  |
| Beam      | 17.5                      | 7.5                               | 25                      | 0.42                  |
| Floor Plate | 7.5                      | 7.5                               | 15                      | 0.25                  |

**Table 12. Calculation of fuel use on cranes**

| Component   | Number of Components | Total Duration per Component | Fuel Usage (liters/hour) | Total Fuel Consumption (liters) |
|-------------|----------------------|-----------------------------|--------------------------|--------------------------------|
| Column      | 24                   | 0.33                        | 27.77                    | 222.16                         |
| Beam        | 51                   | 0.42                        | 27.77                    | 590.11                         |
| Floor Plate | 174                  | 0.25                        | 20.83                    | 906.24                         |
| Total       |                       |                             |                          | 1718.51                        |

\[\text{Energy consumption (TJ) = 1718,51 liters} \times 36 \times 10^{-6} \text{TJ/liters} = 0.061866 \text{TJ}\]

After obtaining the calculation of energy use results, the calculation of greenhouse gas emissions can be carried out by multiplying the amount of energy required by the greenhouse gas emission factor. After that, the total emission of each greenhouse gas is multiplied by the GWP values, which can be seen in Table 13.
Table 13 Result of calculation of emission from transportation and erection

| Source                        | Energy Consumption (TJ) | Emission Amount (kg) | Global Warming Potential (kgCO2eq) |
|-------------------------------|-------------------------|----------------------|------------------------------------|
|                               | a                       | b = a x 74.100 kg/TJ | c = a x 3 kg/TJ                    |
| Transportation (Mobile Combustion) | 0.008405             | 622.81               | 0.03                               |
| Erection (Stationary Combustion)   | 0.061866              | 4584.27              | 0.19                               |

\[ GWP = b + (c x 28) + (d x 265) \]

3.4 Total emission from all sources

The recapitulation of the calculation of greenhouse gas emissions in the precast building construction project can be seen in Table 14.

Table 14. Contribution of precast building project work activities to total greenhouse gas emissions

| Process Drivers | Global Warming Potential (kgCO2eq) | Process Contribution (%) |
|-----------------|------------------------------------|--------------------------|
| Material        | 119.649                            | 95.81                    |
| Transportation  | 632.41                             | 0.51                     |
| Erection        | 4,599.30                           | 3.68                     |
| Total           | 124,882.7                          | 100                      |

The data in Table 14 shows that the amount of greenhouse gas emissions resulting from the material manufacturing, transportation, and erection processes in the precast building construction project is 124,882.7 kgCO2eq. The building has a building area of 441 m² so that the amount of greenhouse gas emissions per unit area is 283.18 kgCO2eq per m² of building with a contribution of emissions from materials of 119,649 kgCO2eq (95.81%), emissions from transportation of precast components of 632.41 kgCO2eq (0.51%), and emissions from the erection of precast components were 4,599.30 kgCO2eq (3.68%). The graph of the amount of greenhouse gas emissions and the contribution of greenhouse gas emissions for each construction material and activity can be seen in Figure 2.

Figure 1. The amount of greenhouse gas emissions in the construction of precast buildings (kgCO2eq)

3.5 Discussion

Several studies indicate that the GHG impact of the embodied emission account for approximately 80-90% of all GHGs released by construction industries [13], [14], [15]. Similarly, embodied emissions from building materials in this research generated the highest contribution to the total GHG emission. A comparison between this study and previous similar research on carbon emissions from buildings is presented in Table 15.
Table 15. Comparison with previous research

| Items                   | This Research                  | Sabaruddin, Karyono and Tobing [4] | Ji Y, Li K, Liu G, Shrestha A and Jing J [16] | Mao C, Shen Q, Shen L and Tang L [15] |
|-------------------------|--------------------------------|------------------------------------|-----------------------------------------------|--------------------------------------|
| Building Type Region    | Precast building               | Reinforced concrete building       | Precast building                              | Precast building                     |
|                         | Yogyakarta                     | Cimahi                             | Chongqing, China                              | Hong Kong                            |
| System Boundary         | Cradle to site                 | Cradle to gate                     | Cradle to site                                | Cradle to site                       |
| Scope of work           | Structural                      | Structural, architectural, MEP     | Structural, architectural                      | Structural, architectural             |
| kgCO2eq per m²          | 283,18                         | 190,72                             | 287.27                                        | 296.56                               |

The result of this study is quite different from the research conducted by Sabaruddin et al due to the differences in the type of building. Besides, Sabaruddin et al only calculate the emissions produced by embodied material without the process of the construction. However, the main reason for the differences between the two research is due to the different values of emission for each material used in the building. While this research using The Inventory of Carbon and Energy (ICE) book by BSRIA [8] as the main source of material value, Sabaruddin et al mostly used emission data values from previous research conducted by Seo and Hwang [17].

The calculation of GHG emission per m² in research conducted by Mao et al [15] shows a big difference with the amount of GHG emission from this research. It is a result of the different scope of work and the amount of GHG emission of each material. The source of emission in [15] was a combination of the Embodied Energy and CO2 Coefficients for NZ Building Materials [18] and the ICE Book. However, there is a significant difference in the amount of steel embodied material in both pieces of research (see Table 16). Meanwhile, the amount of GHG emission per m² from this research was similar to research conducted by Ji et al [16]. However, both research covers the different scope of work and source of emission. The source of emission boundary in Ji et al [16] was based on the research conducted by Mao et al [15].

Table 16. Embodied Material for Each Main Building Material (kgCO2eq)

| Items                     | This Research                  | Sabaruddin, Karyono and Tobing [4] | Mao C, Shen Q, Shen L and Tang L [15] | Ji Y, Li K, Liu G, Shrestha A and Jing J [16] |
|---------------------------|--------------------------------|------------------------------------|--------------------------------------|-----------------------------------------------|
| Precast Concrete          | 0,149                          | Not specified in kgCO2eq per m² unit | Not specified in kgCO2eq per m² unit  | Not specified in kgCO2eq per m² unit          |
| Cast in place concrete    | 0,12                           | Not specified in kgCO2eq per m² unit | 0,12                                | Not specified in kgCO2eq per m² unit          |
| Steel                     | 1,4                            | 0,8515                             | 0,367                                | Not specified in kgCO2eq per m² unit          |

From the research conducted, it was not found a similar pattern of GHG emission per m² of the building. The different result between all the research reviewed was identified due to the difference of LCA processes which lead to different of the scope of work, life cycle inventory, and impact assessment. The differences in the method of construction, distance of material transportation, and heavy equipment used also contribute to the emergence of non-uniform GHG values per m².

Moreover, the difference in the LCA process and system boundaries lead to a different amount of embodied materials. In GHG estimation activities, the accuracy of GHG emission calculations is grouped into three levels of accuracy known as "Tier" where the level of accuracy of calculations is related to the data and calculation methods. Tier determination in GHG estimation is largely determined
by the availability of data and the level of progress of a country or factory in terms of compiling a methodology or determining emission factors that are specific and applicable to that country/factory [4].

As a future work of this research, it is necessary to conduct more detailed research related to the calculation of embodied carbon material from various studies to find out the differences between each of these studies. Embodied materials were proved to be the major contributions to the GHG emission which accounted for 80% to 90% of the total emission. Thus, country-specific research to determine the amount of embodied carbon in construction material is an essential step that needs to be taken by a country to ensure that carbon emissions released by construction projects can be properly recorded and have uniform procedures.

4. Conclusion
The estimated greenhouse gas emissions resulting from the construction project of the precast building is 124,882.7 kgCO₂eq or 283.18 kgCO₂eq per m² building. The emission contribution from materials was 119,649 kgCO₂eq (95.81%), emissions from transportation activities were 632.41 kgCO₂eq (0.51%), and emissions from erection of precast components were 4,599.3 kgCO₂eq (3.68%). The source of GHG emission, type of construction, and the embodied carbon data make a great contribution to the calculation of GHG produced in each construction project.

Acknowledgments
This work is based upon work supported by the Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada.

Reference
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