

# Study of Greenhouse Gas Emission on The Semarang-Demak 1A Toll Road Project

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## Abstract.

*This study estimates carbon dioxide (CO<sub>2</sub>) greenhouse gas (GHG) emissions during the construction phase of the Semarang–Demak Toll Road Project 1A. Motivated by the significant contribution of the infrastructure sector to global GHG emissions, hence the problem formulation is focused on identifying the main emission sources. The aim of the study is to reveal the dominant emission sources and to formulate decarbonization recommendations to reduce environmental impacts and support national emission reduction targets. The study employs a quantitative approach based on the Technical Guidelines for Estimating CO<sub>2</sub> GHG Emissions in Road Construction (No. 07/P/BM/2014) issued by the Directorate General of Highways, Ministry of Public Works and Public Housing, which adapts the IPCC methodology using emission calculation formulas and specific emission factors. Activity data from January 2023 to October 2025 were analyzed according to emission Scopes and work divisions based on General Specifications Revision 3. A qualitative approach complements the analysis by evaluating the effectiveness of decarbonization strategies through observation and document review. The results show total emissions of 6,942,173 tons CO<sub>2</sub>-eq, with Scope 3 dominating 5,688,286 tons CO<sub>2</sub>-eq (81.957%) from Division 10 Concrete Structures due to intensive cement production, Scope 1 at 741,235 tons CO<sub>2</sub>-eq (10.677%), and Scope 2 at 512,652 tons CO<sub>2</sub>-eq (7.385%). Decarbonization strategies include Green Construction, innovation in work methods and technology, BIM integration in Lean Construction, monitoring based on PP No. 22/2021, AMDAL, and RKL-RPL, and the use of renewable energy such as solar power plants (PLTS) and solar panels for Scope 2 electricity supply.*

**Keywords:** CO<sub>2</sub>; GHG emissions and Toll Road Construction.

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## I. INTRODUCTION

Global climate change is one of the most pressing environmental issues that are of concern to various countries, including Indonesia. Increased concentrations of greenhouse gases (GHGs) in the atmosphere, such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (NO<sub>2</sub>), trigger the greenhouse effect that significantly increases the earth's temperature and triggers climate change with far-reaching impacts on environmental, social, and economic aspects (O'Neill & Pidcock, 2021). As a developing country experiencing rapid economic growth and urbanization, Indonesia faces significant challenges in controlling GHG emissions across sectors, including energy, industry, agriculture, transportation, and infrastructure development. Large-scale infrastructure projects such as toll roads are essential for enhancing mobility and economic growth, yet they also contribute to increased GHG emissions from both construction and operational activities. Data from the Central Statistics Agency indicate that Indonesia's national GHG emissions continued to rise during 2019–2023, reaching approximately 1,053,476 Gg CO<sub>2</sub>-eq in 2023. Carbon dioxide (CO<sub>2</sub>) accounts for the largest share at 75%, followed by methane (CH<sub>4</sub>) at 20% and nitrous oxide (N<sub>2</sub>O) at 5% (Badan Pusat Statistik, 2025). In an effort to address these problems, the Indonesian government targets a 29% reduction in GHG emissions by 2030 through a decarbonization strategy, especially in the energy and transportation sectors, although its implementation still faces various technical and regulatory challenges (Deputi Bidang Koordinasi Pengelolaan Energi, 2018).

This effort is also in line with the global agenda of the Sustainable Development Goals (SDGs), especially SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Settlements), and SDG 13 (Handling Climate Change), which emphasizes the integration between economic development and environmental protection (United Nations, 2019). Semarang, the capital of Central Java Province, has complex geographical and climatological characteristics. Located on the northern coast of Java Island, the city covers approximately 373.70 km<sup>2</sup> and is divided into 16 sub-districts, with a varied topography ranging from coastal lowlands to hills reaching 348 meters above sea level. This variation forms Lower Semarang as the center of government and economic activities and Upper Semarang as a hilly and conservation area. These conditions influence GHG dispersion, where hilly areas may inhibit pollutant spread, while lowlands

tend to experience emission accumulation due to limited air circulation (PPID Kota Semarang, 2025). Climatologically, Semarang has a tropical monsoon climate with two main seasons: the rainy season (November–May) and the dry season. Annual rainfall exceeds 2,500 mm, with temperatures ranging from 27.6°C to 34.8°C and relative humidity between 66.93% and 85.64%. Recent climate change—indicated by rising average temperatures and shifts in rainfall patterns—has intensified challenges in managing urban GHG emissions by affecting air circulation and increasing the potential accumulation of atmospheric pollutants (PPID Kota Semarang, 2025).

One of the strategic infrastructure projects in this region is the Semarang–Demak 1A Toll Road Project which aims to improve regional connectivity, reduce congestion, and function as a buffer for flash floods in coastal areas (Kementerian PUPR, 2018). In accordance with the environmentally friendly development policy in Law No. 32 of 2009 concerning Environmental Protection and Management, the infrastructure development must be equipped with an environmental management plan (Kementerian PUPR, 2018). In addition, Presidential Regulation Number 110 of 2025 concerning the implementation of carbon economic value emphasizes the importance of integrating GHG emission control mechanisms in various development sectors, including infrastructure, through the implementation of measurable emission reduction measures (*Peraturan Presiden Republik Indonesia Nomor 110 Tahun 2025 Tentang Penyelenggaraan Instrumen Nilai Ekonomi Karbon Dan Pengendalian Emisi Gas Rumah Kaca Nasional*, 2025). Based on Government Regulation No. 22 of 2021 on Environmental Protection and Management, any activity with significant environmental impact potential must obtain environmental approval through an Environmental Impact Assessment (EIA) or UKL-UPL document. EIA findings indicate that toll road construction and operation can reduce air quality and increase GHG emissions, thereby contributing to the regional carbon footprint. This highlights the need for systematic evaluation of emission levels and the implementation of effective decarbonization strategies in transportation infrastructure projects, particularly in environmentally sensitive areas.

In the context of modern construction, the concepts of Sustainable Construction and Green Construction are important approaches in reducing the environmental impact of development. Sustainable construction emphasizes resource utilization efficiency, waste management, and the use of environmentally friendly materials (Thoengsal, 2024a), while green construction adds aspects of energy conservation, water efficiency, and ecosystem protection such as mangrove forests that play a role in climate change mitigation (Kementerian PUPR, 2023). In addition, the application of Building Information Modeling (BIM) and Lean Construction (LC) technology in construction projects can improve energy efficiency, reduce material waste, and reduce carbon dioxide (CO<sub>2</sub>) emissions through data integration and more effective project management. The integration of these two approaches is able to increase cross-disciplinary collaboration, accelerate project completion, and support sustainable development strategies (Mahardika & Windari, 2025). To systematically assess emission levels, this study applies an estimation method based on the Technical Guidelines for Estimating CO<sub>2</sub> Greenhouse Gas Emissions in Road Development and/or Maintenance Activities issued by the Directorate General of Highways, Ministry of PUPR (No. 07/P/BM/2014). The method adopts the Intergovernmental Panel on Climate Change (IPCC) approach and utilizes relevant emission factors for each stage of road construction, from planning to post-construction (Directorate General of Highways, 2014).

Emission estimation is done by calculating fuel use and other construction activities that produce CO<sub>2</sub> emissions, including the use of heavy equipment, material transportation, and construction material production. The results of the assessment are the basis for formulating an effective decarbonization strategy to reduce the environmental impact of the Semarang-Demak 1A Toll Road project and support the implementation of the National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GHG) in the transportation and transportation sectors. (Ministry of National Development Planning/Bappenas, 2023). However, the implementation of decarbonization strategies in the field is often not optimal due to the limitations of low-carbon technology, technical constraints, and lack of coordination between stakeholders. This condition shows that there is a gap between national policy targets and the realization of their implementation in the field (Febrianti et al., 2023). In addition to these empirical conditions, studies on

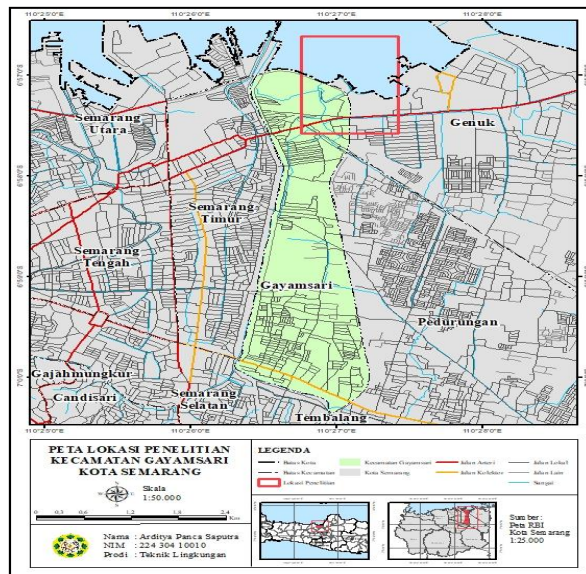
greenhouse gas emissions in toll road infrastructure projects have been carried out extensively, but they still have some limitations. Research by (Wulandari, 2024) analyzed CO<sub>2</sub> emissions across pre-construction, production, and construction stages, identifying material production and construction activities as the largest contributors.

Meanwhile, research (Yahya et al., 2025) emphasized the role of green open space (RTH) along the Jagorawi Toll Road corridor in absorbing vehicle-generated CO<sub>2</sub>, focusing on mitigation during the operational stage. Other research by (Kurnia W. et al., 2022) and (Soeryodarundio et al., 2023) applied the Life Cycle Assessment (LCA) approach, highlighting construction material production and transportation as major emission sources. In addition, Suhardono et al.'s (2025) research examined the influence of environmental factors on carbon monoxide (CO) concentrations around toll road construction, with a greater focus on local air quality than total carbon emission estimation. Although these studies provide important insights into emission sources in construction and transportation sectors, most focus on general emission analysis, LCA-based approaches, or air quality assessments around projects. Research that specifically examines CO<sub>2</sub> emission estimation at the construction stage using national technical guidelines from the Directorate General of Highways, adapted from the IPCC methodology, remains limited. This gap is particularly evident in the Semarang–Demak 1A Toll Road Project, which has unique coastal characteristics and an additional function as a tidal flood barrier. Based on these conditions, this study examines the estimated level of carbon dioxide (CO<sub>2</sub>) greenhouse gas (GHG) emissions at the construction stage of the Semarang–Demak 1A Toll Road Project. The background of the research is based on the contribution of the infrastructure sector to the increase in global GHG emissions, so the formulation of the problem is focused on the identification of the main sources of emissions in construction activities. The purpose of this research is to identify the dominant sources of emissions and formulate recommendations for decarbonization strategies that can reduce environmental impacts while supporting the achievement of national targets to reduce greenhouse gas emissions.

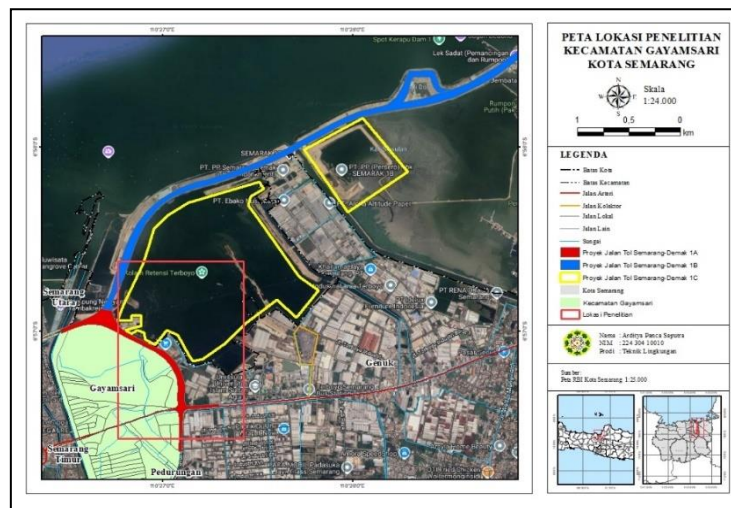
## II. METHODS

### Place and Time of Research

The research was conducted at the location of the Semarang-Demak 1A Toll Road Project, Gayamsari District, Semarang City, Central Java Province. This location was chosen because it is a national strategic project that is in the active stage of implementation and has the potential for environmental impacts, especially related to greenhouse gas emissions during the construction process. Data-specific locations include heavy equipment work areas, material warehouses, and project material transportation routes. Here is a map of the research location:



**Fig 1.** Map of the Research Location  
(Source: Hutama Karya, 2025)



**Fig 2.** Map of the Semarang-Demak 1A Toll Road Research and Project Location  
(Source: Hutama Karya, 2025)

The research time is planned to take place during the active construction period of the Semarang-Demak 1A Toll Road Project, which is from January 2023 to October 2025. During this time frame, the research will include continuous primary and secondary data collection related to key construction activities, as well as data analysis for the assessment of greenhouse gas emissions.

**Research Variables**

**Table 1.** Research Variable and Indicators

Yes	Variable	Operational Specifications	Indicator	Measurement Method
1	GHG Emissions (CO2-eq)	Total equivalent carbon dioxide emissions resulting from construction activities, including heavy equipment, material transportation, and material production	Tons of CO2 equivalent	The calculation uses IPCC and PUPR technical guidelines based on fuel consumption and material volume data
2	Construction activities by division of work	All physical activities in construction projects are based on the category of distribution of toll road construction work according to the General Specifications of Revision 3, for example, earthworks, pavement, bridges, and others.	Volume/material, km, ton	Direct observation and field notes
3	Diesel Fuel Consumption	The amount of diesel fuel used by the machine during a construction project	Liters of diesel used by heavy machines	Direct observation and field notes
4	Use of Eco-Friendly Materials	The percentage of use of construction materials that have environmentally friendly and low-emission certifications	% volume/weight of eco-friendly materials to total materials	Interviews, project reports, documentation
5	Operational Efficiency	The level of time efficiency and the use of tools and labor in the construction stage	Effective working time, number of active machines	Field data and monitoring systems
6	Decarbonization strategy	Emission reduction technologies and methods applied during construction, such as the use of efficient heavy equipment and innovative construction technologies	Qualitative/descriptive	Observations, interviews, documentation

**Population and Sample**

The population in this study comprises all construction activities in the Semarang–Demak 1A Toll Road Project, including data on material usage and related energy consumption during the research period as recorded in the BoQ (Bill of Quantity) document. The sample was determined using purposive sampling by selecting primary and secondary data that are relevant and representative of the research objectives. The selected data include information on heavy equipment usage, types and volumes of construction materials, and the consumption of electrical energy and fuel, primarily derived from the BoQ document.

### Research Data and Instruments

The data used in this study consisted of primary and secondary data, which complement each other in supporting the analysis of greenhouse gas (GHG) emissions during the construction stage of the Semarang–Demak 1A Toll Road Project. Primary data were collected through field-based techniques, including direct observation to inventory heavy equipment usage, diesel fuel consumption, and the type and quantity of construction materials. Project operational activities were also recorded, covering equipment usage duration and construction work volume, and complemented by interviews with project personnel to obtain detailed information on construction processes and patterns of energy and material use. Secondary data were obtained from relevant official sources, including project documents such as EIA and HSE reports, environmental monitoring reports from contractors, energy consumption reports, and emission inventories prepared in accordance with national standards. This study also applied emission standards and factors from Regulation of the Minister of Public Works and Public Housing No. 9 of 2021, the Technical Guidelines for Estimating CO<sub>2</sub> Emissions issued by the Directorate General of Highways (No. 07/P/BM/2014), and Presidential Regulation No. 110 of 2025, supported by relevant scientific literature and previous studies at national and international levels.

#### Data Collection Techniques

Data in this study were collected using several methods to obtain accurate and relevant information on greenhouse gas (GHG) emissions in the Semarang–Demak 1A Toll Road Project.

- a. Field Observation (*Direct Observation*): Conducted at the construction site to record heavy equipment usage, operational duration, diesel fuel consumption, and the volume of construction materials, providing quantitative data on emission-generating activities.
- b. Structured Interview: Interviews with project personnel, including project managers, field supervisors, and heavy equipment operators, were carried out to gather detailed information on work processes, energy use, and the implementation of decarbonization strategies.
- c. Documentation and *Document Review*: Secondary data were obtained from project documents such as energy and fuel consumption reports, environmental reports, EIA documents, and contractor records related to material usage and emission inventories, including official emission standards and factors from relevant agencies.
- d. Survey and Questionnaire: When necessary, surveys of workers or project staff were conducted to assess perceptions and understanding of emission reduction efforts and environmentally friendly technologies.
- e. Technical Data Measurement and Monitoring: Project data were utilized to monitor fuel consumption, equipment work intensity, and digital records from project monitoring systems.

#### Data Analysis Techniques

After the data is obtained from primary data from field observations and interviews, as well as secondary data from project documents and emission standards, the next stage is an analysis process using the emission factor-based greenhouse gas emission calculation method in accordance with the "Technical Guidelines for Estimating CO<sub>2</sub> Greenhouse Gas Emissions in Road Development and/or Maintenance Activities" of the Directorate General of Highways of the Ministry of PUPR. Some of the follow-up tahapan carried out include:

- a. Data Classification and Determination of *Analytical Scope*

Emission data is classified based on emission sources, namely direct *emissions* from activities at construction sites and indirect *emissions* from material production and external energy consumption. The scope of the analysis includes the pre-construction stage, material production, and construction in the field (*cradle to gate*).

- b. Greenhouse Gas Emissions Estimates

Estimation of carbon dioxide (CO<sub>2</sub>) greenhouse gas (GHG) emissions using quantitative data on fuel consumption, material volume, heavy equipment operational duration, and official emission factors from the Technical Guidelines for Estimating CO<sub>2</sub> Greenhouse Gas Emissions in Road Construction and/or

Maintenance Activities" (Directorate General of Highways of the Ministry of PUPR No. 07/P/BM/2014).

The basic formula for estimating GHG emissions is as follows:

The basic formula for estimating GHG emissions is as follows:

$$\text{GHG emissions} = \text{DA} \times \text{FE} \dots\dots\dots (1)$$

Description:

- DA : Data on development activities that produce GHG emissions
- FE : GHG emission factors that show the amount of emissions per unit of activity carried out

The GHG emission estimation formula applied in the engineering guide is as follows:

$$\text{GHG Emissions} = \text{Energy Consumption} \times \text{Emission Factors} \dots\dots\dots (2)$$

Description:

- GHG Emissions (kg)
- Energy Consumption (Terra Joule)
- Emission Factor (kg/Terra Joule)

Since the energy consumption data is generally available in physical units such as diesel fuel in liters, the above formula must be converted in energy units (TJ = Terra Joule) using the following equation:

$$\text{Energy Consumption (TJ)} = \text{Energy Consumption (physical units)} \times \text{Calorific Value \{TJ/sat.physical\}} \dots\dots\dots (3)$$

c. Evaluation and Simulation of Decarbonization Strategies

Based on the results of the analysis, an evaluation of the effectiveness of the current decarbonization strategy and simulation of alternative emission reduction scenarios, such as the substitution of fossil fuels with biofuels, the application of technology or the use of environmentally friendly materials, were carried out.

d. Data Reporting and Interpretation

The results of the analysis are presented in the form of tables, graphs, and narratives that explain the amount of emissions, the main sources of emissions, and recommendations for emission reduction. Data interpretation refers to the research objectives and conceptual framework that have been set.

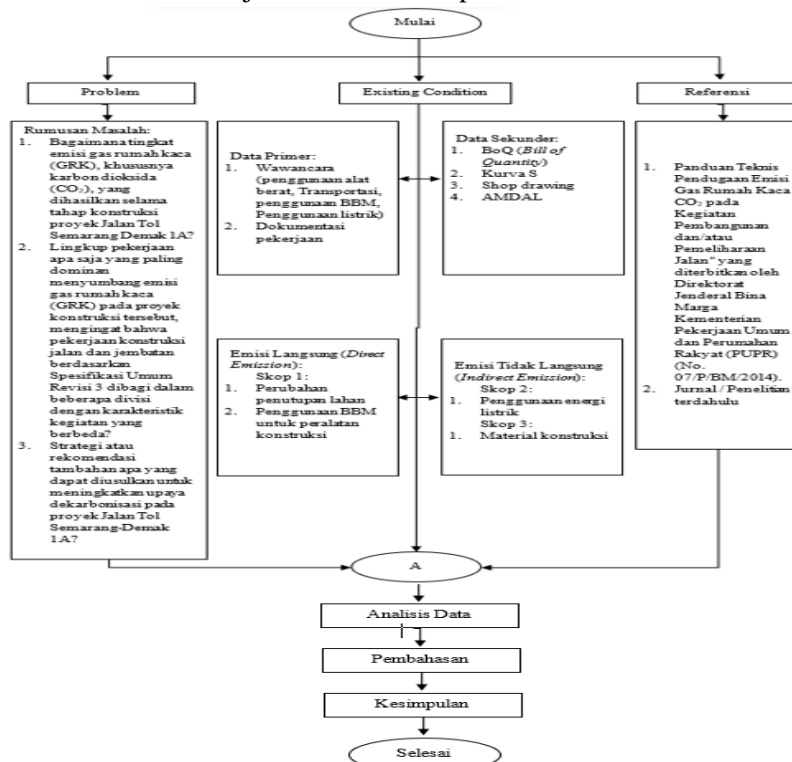


Fig 3. Research Framework

### III. RESULT AND DISCUSSION

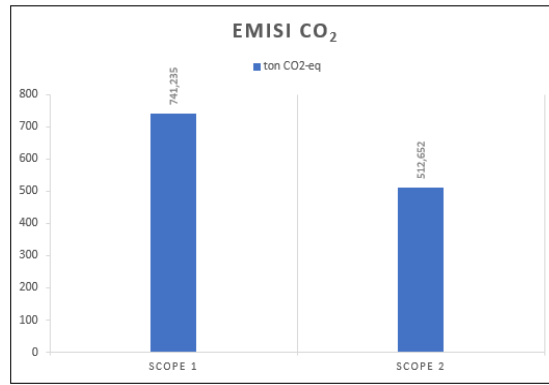
#### Comparison of Greenhouse Gas Emission Levels in the Scope of Work

Based on the data collected and the analysis of the assessment of carbon dioxide (CO<sub>2</sub>) greenhouse gas (GHG) emissions in the Semarang-Demak 1A Toll Road Project.

**Table 2.** Greenhouse Gas (GHG) Emissions Summary

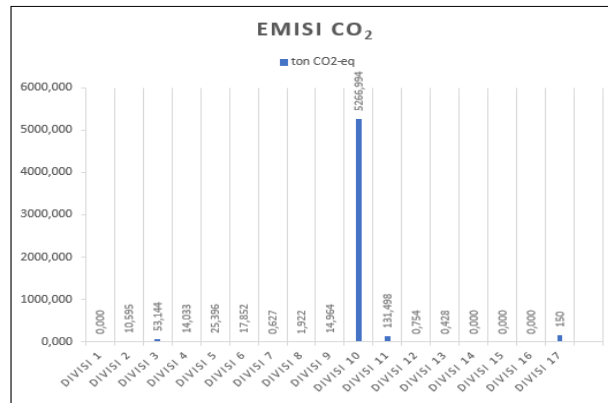
No.	Job Details	Total Emissions (tonnes CO <sub>2</sub> -eq)	Introduce yourself
<b>1</b>	<b>Scope 1. Direct Emissions</b>		
1.1	Operational Fuel Use	737,615	10,625%
1.2	Usage of LPG	3,620	0,052%
<b>Total</b>		<b>741,235</b>	<b>10,677%</b>
<b>2</b>	<b>Scope 2. Indirect Emissions</b>		
2.1	Electricity Use	512,652	7,385%
<b>Total</b>		<b>512,652</b>	<b>7,385%</b>
<b>3</b>	<b>Scope 3. Indirect Emissions</b>		
3.1	Division 1 General	0,000	0,000%
3.2	Division 2 Workplace Cleaning	10,595	0,153%
3.3	Division 3 Demolition	53,144	0,766%
3.4	Division 4 Earthworks and Geosynthetics	14,033	0,202%
3.5	Division 5 Structure Excavations	25,396	0,366%
3.6	Division 6 Drainage	17,852	0,257%
3.7	Division 7 Subgrade	0,627	0,028%
3.8	Division 8 Layer Aggregate Foundation and Cement Aggregate Foundation Layer	1,922	0,028%
3.9	Division 9 Pavement	14,964	0,216%
3.10	Division 10 Concrete Structure	5,266,994	75,870%
3.11	Division 11 Structural Steel Works	131,498	1,894%
3.12	Division 12 Miscellaneous Occupations	0,754	0,011%
3.13	Division 13 Traffic Light Lighting and Electrical Works	0,428	0,006%
3.14	Division 14 Toll Plaza	0,000	0,000%
3.15	Division 15 Diversion and Protection of Existing Utilities	0,000	0,000%
3.16	Division 16 Toll Offices and Facilities	0,000	0,000%
3.17	Division 17 Day Work	150,080	2,162%
<b>Total</b>		<b>5,688,286%</b>	<b>81,957%</b>
<b>TOTAL GHG EMISSIONS</b>		<b>6,942,173</b>	<b>100%</b>

Based on Carbon Emission data collected from the Semarang-Demak 1A Toll Road Project in the period January 2023-October 2025, the total carbon dioxide (CO<sub>2</sub>) greenhouse gas (GHG) emissions reached 6,942,173 tons of CO<sub>2</sub>-eq which are divided into three *Scopes*, namely: *Scope 1* (direct emissions), *Scope 2* (indirect emissions), and *Scope 3* (indirect emissions from the entire Scope of Work Based on the General Specification Classification of Revision 3 Road and Bridge Works). Emissions in *Scope 1*, which include the use of operational fuel oil (BBM) and LPG, account for 10.677% of the total emissions of 741.235 tons of CO<sub>2</sub>-eq. *Scope 2*, which comes from the project's electricity consumption, contributes 7,385% for a total of 512,652 tons of CO<sub>2</sub>-eq. Here are the total *Scope 1* and *Scope 2* Carbon Emissions based on the graph:



**Fig 4.** Scope 1 and Scope 2 Carbon Emissions

However, the largest contribution is in *Scope 3*, which is indirect emissions from the scope of construction work, which reaches 81.957% of total emissions or the equivalent of 5,688,286 tons of CO<sub>2</sub>-eq. Within *this Scope 3*, the scope of work of Division 10 Concrete Structure dominates with an emission value of 75.870% equivalent to 5,266,994 tons of CO<sub>2</sub>-eq, indicating that concrete structure work is the main contributor to carbon emissions in this project. Other divisions such as structural steelwork and day jobs also made smaller but still significant contributions. Here are the total *Scope 3* Carbon Emissions based on the graph:



**Fig 5.** Scope 3 Carbon Emissions

Analysis of the results and research methods of greenhouse gas (GHG) emissions in the Semarang-Demak 1A Toll Road Project with a comparison of the results of the research case study (Alnu Fistcar, 2021) and (Annisa Wulandari, 2024) can be used to obtain a quantitative picture of what scope of work is the most dominant contributor to the main source of emissions. This allows the development of more effective decarbonization strategies to reduce greenhouse gas (GHG) emissions. Previous research has also emphasized the importance of accurate activity data and emission factors to support the validity of greenhouse gas emission analysis results. In this study, the analysis of greenhouse gas (GHG) emissions in the Semarang-Demak 1A Toll Road Project produced a total 6.942,173 tonnes of CO<sub>2</sub>-eq, with a dominance of *Scope 3* especially Division 10 Concrete Structure which reaches 81.957% or 5.688,286% your CO<sub>2</sub>-eq. These findings are in line with the study (Alnu Fistcar, 2021) on the Balikpapan-Samarinda Toll Road, where concrete production at the batching plant plant is the largest contributor to emissions (63-85% of the total 1,113-1,225 tons of CO<sub>2</sub>-eq for the 1 km concrete segment, compared to 208-380 tons of CO<sub>2</sub>-eq for asphalt).

Although the scale of this research project is wider so that the absolute emissions are higher, the pattern of concrete emission intensity which is 5-6 times that of asphalt confirms the similarity of the main source, namely the cement-intensive material production process. The methodology of this study adopts the *Scope 1*, *Scope 2*, *Scope 3* based on activity data from 17 work divisions, with *Scope 1* (fuel and LPG) contributed 10,677% and *Scope 2* (electricity) 7.385%, while the study (Alnu Fistcar, 2021) Apply *Life Cycle Assessment (LCA)* through two methods, namely *Table Energy Use & GHG Emissions for Pavement Construction* as well as IPCC fuel conversion on the production-transportation-construction cycle. Low

contribution of transportation and construction (<20% to Alnu Fistcar, <20% *Scope 1* dan *Scope 2* in this study) with other studies such as (Annisa Wulandari, 2024) on the Serang-Panimbang Toll Road, which also highlighted material production as a hotspot *Global Warming Potential (GWP)*. The accuracy of energy consumption and emission factor data is the foundation for the validity of cross-project comparisons.


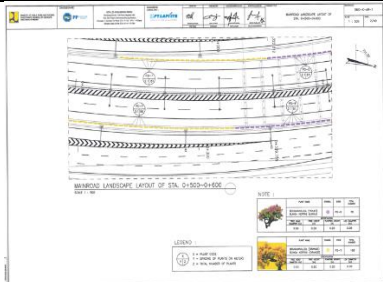

**Decarbonization Strategy**

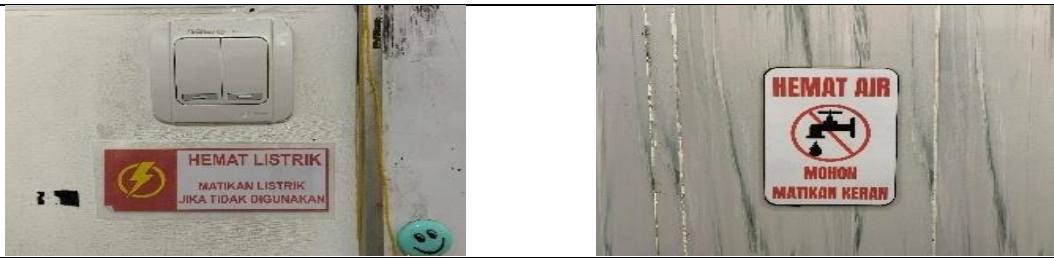
Decarbonization is the process of reducing or eliminating greenhouse gas (GHG) emissions, especially carbon dioxide (CO<sub>2</sub>), from human activities through the transition from fossil fuels to renewable energy, energy efficiency, and low-carbon technological innovation. In the context of Indonesia's construction, Ilham Akbar Habibie (Chairman of PII, 2025) defines decarbonization as "a green transition in construction that is part of the *Regenerative Reindustrialization* and *Human Centric*." for sustainable infrastructure development (Arnidhya Nur Zhafira, 2025). In the Semarang-Demak 1A Toll Road Project, the decarbonization strategy includes an implementation approach *Green Contruction*, application of working methods, application of technology, application of *Building Information Modeling (BIM)* on *Lean Construction (LC)*, as well as the implementation of Environmental Monitoring and Management.

**A. Decarbonization Strategy**

According to (Thoengsal, 2024), the main characteristics of green construction include energy efficiency and water conservation, effective waste management, use of environmentally friendly materials, and indoor air quality control. (Mahardika et al., 2025) affirms that the implementation of *Green Construction*, part of sustainable construction, involves technical planning ranging from impact management, energy and water use efficiency, use of environmentally friendly materials, to waste and wastewater management. The application of technologies such as green concrete and the use of recycled materials are increasingly being applied to reduce environmental impact. Based on the research that has been done (Atlanta Falcons, 2025) About the application *Green Toll Road* In the Semarang-Demak Toll Road Project Package 1A, analysis of 93 indicators showed varied achievements between categories: Transportation and Community met 16 out of 33 indicators (17%), Environmental Management 17 out of 26 indicators (18%), and Construction Activities with 31 out of 34 indicators (33%). Overall, the fulfillment rate reached 68%, which was classified as "adequate" to "good". The following is the application *Green Contruction* on the Semarang-Demak Toll Road 1A Project:

**Table 4. 1.** Implementation of Green Contruction

No	Captions and Pictures
1	<p data-bbox="284 1308 1445 1361">Planting Bougainvillea trees on the median of the Semarang-Demak Toll Road 1A (according to DED) is useful for carbon sequestration</p> <div data-bbox="284 1364 764 1637">  <p data-bbox="284 1364 764 1637">7 Nov 2024 17:34:30 Mukuharjo Lor Kecamatan Genuk Kota Semarang Jawa Tengah Proyek Toll Semarang-Demak 1A BUCG HK-10</p> </div> <div data-bbox="971 1368 1355 1648">  </div>
2	<p data-bbox="284 1659 1445 1713">Planting trees of <i>Calathea Lutea</i>, <i>Hibiscus Schizopetalus</i>, <i>Terminalia Mantaly</i>, <i>Salvia Farinacea</i> in the office area of the Semarang-Demak Toll Road Project 1A is useful for carbon sequestration</p> <div data-bbox="284 1715 1426 1968">  </div>
3	<p data-bbox="284 1973 1315 2002">Carry out electricity and water saving campaigns by installing stickers to save energy and water.</p>



Use of non-CFC air conditioners

4



Use of Turbine Ventilators for energy-efficient ventilation

5



Use of energy-efficient LED lights

6



Utilization of construction materials or reuse of existing materials

7



### B. Application of Work Methods, Technology, and Innovation

The application of work methods, technology, and innovation in Green Toll Road Reduce Emissions Scope 1 significantly through the electrification of heavy equipment and solar power plants off-grid. In his research, (Santosa & Lawalata, 2019) stated, "The Green Road Program has the potential to reduce carbon emissions by 28-37% via renewable pavement innovations", in line with the analysis (Firmawan & Anggraini, 2026) which achieved 78% of the indicators in Section 2 of Semarang-Demak. In the Semarang-Demak 1A Toll Road Project, the integration of advanced work methods, digital construction technologies, and innovative approaches represents a strategic effort to enhance efficiency, quality, and sustainability. Beyond physical construction, these approaches enable more timely and cost-controlled project management while supporting safety and user comfort. The following outlines the implementation of work methods, technologies, and innovations that contribute to reducing reliance on conventional heavy equipment.

a. Application of Sosrobahu Technology

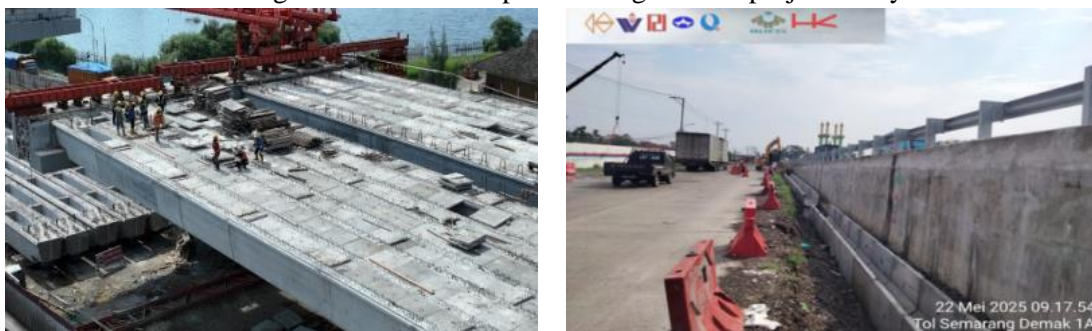
The application of Sosrobahu technology in the Semarang–Demak 1A Toll Road Project represents both a construction innovation and an effective strategy to reduce project duration. This method enables the pier head to be constructed parallel to the arterial road and then rotated 90 degrees into its final position using a hydraulic system, thereby avoiding disruption or closure of congested traffic lanes (Rochimawati, 2025). This approach significantly accelerates construction by eliminating the need for prolonged road closures and minimizing disruptions to surrounding social and economic activities. In addition to time efficiency, it supports decarbonization efforts by reducing the need for conventional traffic management, which typically requires additional equipment and fuel, and by minimizing emissions associated with congestion during road closures (Rochimawati, 2025).



**Fig 6.** Application of Sosrobahu Technology  
(Source: Author Documentation, 2025)

b. Uses of Precast Concrete

The use of precast concrete supports the construction decarbonization strategy through the controlled production of material components in the factory, so that only quick installation is carried out at the project site without casting and *Curing in Situ*. (Anuna et al., 2023) state that precast concrete with a green building concept can reduce construction waste by up to 50% compared to conventional methods, while accelerating implementation and minimizing emissions from diesel-powered heavy equipment, while (Haryati & Hermawan, 2021) emphasized that in precast reinforced concrete work, larger volumes lead to lower costs and faster execution, with cost savings of up to 25.34% and time savings of 11.11% in the BPJS Central Jakarta building project. In the Semarang–Demak 1A Toll Road Project, the use of precast elements such as U-Ditch drainage, panel slabs, and Precast Concrete Units (PCU) represents a construction innovation that reduces reliance on heavy equipment and eliminates time-consuming in situ casting activities. With materials produced under controlled factory conditions, on-site work is limited to installation, thereby minimizing construction waste and reducing environmental impacts throughout the project lifecycle.



**Fig 7.** Precast Concrete

(Source: Author Documentation, 2025)

c. Implementation of Just In Time Work Methods

Implementation of work methods *Just In Time* (JIT) on construction projects such as the Semarang–Demak 1A Toll Road ensures that material and resource efficiency is available on time, avoiding build-up and waste. (Hidayat, Rahmat, 2024) in the case study of UIN Malang Phase II stated that "JIT reduced the average volume of reinforcement steel shipments from 57,486 kg to 25,984 kg per arrival, increased the

frequency of shipments 14-28 times with an interval of 4.2 days, and reduced traveling distance by 6.81% through layout optimization", in line with *Lean Construction* which minimizes transportation emissions and field waste. JIT approach in line with principles *Green Toll Road Construction Activity* category (33% indicator fulfillment), where scheduled deliveries reduce the need for diesel heavy equipment *Scope 1*. (Istiqomah et al., 2023) emphasizing that "the implementation of JIT improves operational efficiency and cost control through the reduction of excess inventory and improvement of material quality".



**Fig 8.** Work Monitoring Schedule







Decarbonization strategies can be supported through the use of renewable energy, particularly Solar Power Plants (PLTS). According to (Nugraha et al., 2024) considering that Central Java has a solar energy potential of 8,753 MW based on the National Energy General Plan (RUEN). A case study on a 5 kWp solar PV grant installed in Islamic boarding school buildings shows an annual energy output of 7.13–7.30 MWh (based on GSA and PVWatts simulations), reducing CO<sub>2</sub> emissions by 138.5–141.7 tons over a 25-year lifespan, with a payback period of 22.8–24.8 years through electricity cost savings. Furthermore, a technoeconomic study of a 166.16 kWp rooftop solar PV system at the Central Java Provincial Secretariat Building demonstrates feasibility, with a positive NPV and BCR greater than 1, supporting energy efficiency in government buildings. This implementation complements on-grid solar PV installations at the ESDM Office (35 kWp), Bappeda (30 kWp), and the Central Java DPRD (30 kWp). The use of non-TKDN materials in non-social buildings can further accelerate the payback period by 8–8.4 years (Aribowo & Nugraha, 2025).

#### d. Application of BIM in Lean Construction

Application *Building Information Modeling* (BIM) on *Lean Construction* (LC) in the Semarang-Demak 1A Toll Road Project is one of the technological innovations that supports optimal construction efficiency and management. BIM enables the integration of project data and information in one coordinated digital platform, so that all stakeholders can collaborate in a coordinated manner. *real-time* and reduce miscommunication or planning errors (Son, 2025). Combined with the principle *Lean Construction* that focus on reducing waste (*Waste*) and increased productivity through systematic work management such as *Last Planner System* (LPS), BIM helps optimize the process of planning, scheduling, and implementing projects (Yulius Chaesario Kurniawan & Nectaria Putri Pramesti, 2024). In the context of the Semarang-Demak Toll Road, the application of BIM in the *Lean Construction* has been proven to improve project management time efficiency with achievements *Percent Plan Complete* (PPC) above 96%, exceeding the industry-standard target of 85%. (Fitzgerald, 2025) in UMY's thesis on installation *Geotube* states that "the application of *Last Planner System* Improve team coordination and reduce *Rework* due to material delays of up to 40% in the condition of Semarang-Demak soft soils", showing high adaptation to field dynamics. (PT. Hutama, 2024) in transformation *Lean Digital Construction* asserts "BIM enables *real-time* materials and progress, increase productivity by 25% while reducing construction waste", supporting the PSN decarbonization strategy through human resource competency development and structured training.



**Table 4. 2.** Environmental Monitoring and Management  
(Source: Hutama Karya, 2025)

No.	Remarks	Image
1	Environmental quality standard testing based on Government Regulation No. 22 of 2021	 <p>A photograph showing environmental testing equipment (noise and air quality monitors) set up on a road. Two workers in blue uniforms and hard hats are standing near the equipment. The scene is outdoors with trees and a clear sky.</p>
2	Dust control by cleaning soil/dust on public roads, and regular road watering	 <p>Two photographs illustrating dust control measures. The top photo shows a worker in an orange safety vest using a high-pressure water hose to clean a wet road surface. The bottom photo shows a worker in blue overalls and a yellow hard hat cleaning a gravel area with a broom. Both photos include logos of various organizations at the bottom.</p>
3	Closing the truck material using tarpaulin	 <p>A photograph of a blue truck with its cargo bed covered by a blue tarpaulin. A worker is visible near the truck. The image includes a timestamp '13/05/2025 14:26:34' and the text 'Proyek Toll Semarang Demak Paket 1A'.</p>
4	Waste transport	 <p>A photograph showing a worker in a white uniform and green hard hat loading waste into a blue truck. Another worker in an orange safety vest is standing nearby. The truck has a yellow and black striped container on its bed.</p>
5	Preparation of 3-color bins	 <p>A photograph of three waste bins (red, yellow, and green) with corresponding signs. The red sign says 'SAMPAH B3' (Hazardous Waste), the yellow sign says 'SAMPAH ANORGANIK' (Inorganic Waste), and the green sign says 'SAMPAH ORGANIK' (Organic Waste). The bins are placed on a concrete surface.</p>
6	Provision of B3 waste TPS	 <p>A photograph of a waste transfer station (TPS) for B3 waste. The sign above the entrance reads 'TPS Limbah B3'. There are several blue and red bins in the foreground, and a worker is visible near the entrance. The station is enclosed with a fence.</p>

No.	Remarks	Image																												
7	Using heavy material and equipment transportation vehicles that are roadworthy and functional, as well as the equipment used has gone through emission testing.	<p>PerMenLH No 5 Tahun 2006 Tentang Ambang Batas Emisi Gas Buang Kendaraan Bermotor Lama</p> <p><b>Kendaraan Bermotor Kategori M dan N</b></p> <p><b>Kendaraan Bahan Bakar Bensin</b></p> <table border="1"> <thead> <tr> <th>Kategori</th> <th>Parameter</th> <th>HC</th> <th>CO<sub>2</sub>(%)</th> </tr> </thead> <tbody> <tr> <td>Ambang Batas Emisi</td> <td>&lt;2007</td> <td>1200</td> <td>4,5</td> </tr> <tr> <td></td> <td>≥2007</td> <td>200</td> <td>1,5</td> </tr> <tr> <td>Hasil Uji</td> <td></td> <td></td> <td></td> </tr> </tbody> </table> <p><b>Kendaraan Bahan Bakar Solar</b></p> <table border="1"> <thead> <tr> <th>Kategori</th> <th>Parameter</th> <th>Opasitas</th> </tr> </thead> <tbody> <tr> <td>Ambang Batas Emisi</td> <td>&lt;2007</td> <td>70</td> </tr> <tr> <td></td> <td>≥2007</td> <td>40</td> </tr> <tr> <td>Hasil Uji</td> <td></td> <td></td> </tr> </tbody> </table> <p><b>Keterangan Hasil Uji Emisi</b></p> <p><input checked="" type="checkbox"/> <b>LULUS</b> (di bawah Ambang Batas Emisi)</p> <ul style="list-style-type: none"> <li>* Lanjutkan service secara teratur</li> </ul> <p><input type="checkbox"/> <b>TIDAK LULUS</b> (di atas Ambang Batas Emisi)</p> <ul style="list-style-type: none"> <li>* Bersihkan atau ganti saringan udara &amp; BBM</li> <li>* Ganti oli dan filter oli</li> <li>* Segera lakukan perbaikan di bengkel</li> </ul> <p><b>TERIMA KASIH ATAS PARTISIPASI ANDA</b> uji kualitas lingkungan bersama CDULab</p> <p>cdulab.co.id</p>	Kategori	Parameter	HC	CO <sub>2</sub> (%)	Ambang Batas Emisi	<2007	1200	4,5		≥2007	200	1,5	Hasil Uji				Kategori	Parameter	Opasitas	Ambang Batas Emisi	<2007	70		≥2007	40	Hasil Uji		
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#### IV. CONCLUSION

Based on the analysis of the Semarang–Demak 1A Toll Road Project, total CO<sub>2</sub> greenhouse gas (GHG) emissions during the construction phase reached 6,942,173 tons CO<sub>2</sub>-eq for the period January 2023 to October 2025. These consist of Scope 1 emissions of 741,235 tons CO<sub>2</sub>-eq (10.677%), Scope 2 of 512,652 tons CO<sub>2</sub>-eq (7.385%), and Scope 3 of 5,688,286 tons CO<sub>2</sub>-eq (81.957%). The largest contribution originates from Division 10 Concrete Structures under Scope 3, amounting to 5,266,994 tons CO<sub>2</sub>-eq (75.870%), primarily driven by the high intensity of cement use in concrete production. Other divisions, including structural steel works (1.894%) and daily works (2.162%), contribute relatively minor emissions based on the General Specification of Revised 3 Road and Bridge Works. Decarbonization efforts implemented in the project include Green Construction practices, innovation in work methods and technology, the application of Building Information Modeling (BIM) within Lean Construction, and environmental management based on Government Regulation No. 22/2021, AMDAL, and RKL-RPL.

To enhance emission reduction effectiveness, several strategies are recommended: substituting conventional concrete with low-clinker green cement or fly ash/slag mixtures, utilizing biofuels in heavy equipment to reduce Scope 1 emissions, and adopting renewable energy such as Solar Power Plants (PLTS) for Scope 2 operations. Furthermore, optimizing Just In Time (JIT) and BIM–Lean Construction is essential to reduce transportation-related emissions under Scope 3. The development of Green Open Space (RTH) through planting high carbon-absorbing species such as *Bougainvillea* and *Terminalia mantaly* with a target of 10–30% land coverage is also recommended as a long-term carbon offset strategy. These measures should be supported by periodic audits based on the Life Cycle Assessment (LCA)-IPCC framework, collaboration with stakeholders in cement decarbonization initiatives, and continuous monitoring of AMDAL and RKL-RPL to support Indonesia’s NDC 2030 targets and sustainable infrastructure development.

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