Sustainable Civil Building Management and Engineering Journal Vol: 2, No 1, 2025, Page: 1-10

Greenhouse Gas Emission Analysis Using the Life Cycle Assessment Method for the CO2 Compressor Machine Foundation at PT Kaltim Methanol Industri

Rifki Hardianto[1]*, Setiono, Fajar Sri Handayani[2]

[12] Civil Engineering Study Program, Faculty of Engineering, Sebelas Maret University

DOI: https://doi.org/10.47134/scbmej.v2i1.3580
*Correspondence: Rifki Hardianto
Email: rifkihard01@student.uns.ac..id

Received: 20-11-2024
Accepted: 20-12-2024
Published: 21-01-2025

Copyright: © 2025 by the authors. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

Abstract: Climate change and global warming have become major global concerns due to their significant impacts on the environment and human life. One of the primary contributors to climate change is Greenhouse Gas (GHG) emissions, which are generated by various industrial activities, including the construction sector. PT Kaltim Methanol Industri, one of Indonesia's largest methanol producers, plans to add a new unit for CO_2 injection to enhance its production capacity. In this new unit, the reciprocating compressor machine foundation is a crucial structural component that must not only meet technical requirements but also consider environmental impacts, particularly GHG emissions produced during the construction process. This study employs the Life Cycle Assessment (LCA) method to identify the life cycle stages that contribute the most to GHG emissions and and to determine the most environmentally friendly foundation among various types of foundation, namely standard block foundation, spring-supported foundation type 1, type 2, and type 3. The dimensions of each foundation type are 10.2 m in length and 6.2 m in width, with varying heights: standard block foundation (1.5 m), spring-supported type 1 (1.25 m), spring-supported type 2 (1.0 m), and spring-supported type 3 (0.75 m). The height above ground for each foundation type is 0.35 m. The study results indicate that the raw material stage contributes the most emissions, with the highest emissions recorded in the standard block foundation at 65,969.8476 $kgCO_2e$. Meanwhile, the foundation with the lowest emissions is the spring-supported type 3, producing 36,550.0597 $kgCO_2e$.

Keywords: Greenhouse Gas Emissions, Life Cycle Assessment, Machine Foundation

Introduction

Climate change and global warming have become major global concerns due to their significant impacts on the environment and human life. One of the primary contributors to climate change is Greenhouse Gas (GHG) emissions resulting from various industrial activities, including the construction sector. According to the United Nations Environment Programme (2021), the construction sector contributes up to 37% of total global GHG emissions. In an effort to reduce GHG emissions, industries are expected to implement various mitigation measures, including optimizing operational processes and improving efficiency in the construction sector.

PT Kaltim Methanol Industri, as one of the largest methanol producers in Indonesia, plans to add a new unit for CO_2 injection to increase its production capacity. In this new unit, the foundation of the reciprocating compressor machine is a critical structural component. This foundation must not only meet technical requirements but also take into account environmental impacts, particularly the GHG emissions generated during its construction process. Each phase of construction, from the raw materials to usage during construction, contributes to the increase in GHG emissions, which are the primary drivers of global climate change. Machine foundations are structures designed to support the static and dynamic loads generated by the machinery they hold. Standard block foundations are designed to have sufficient mass to withstand the dynamic forces of the machine. According to Addina S. A. (2022), the larger the foundation dimensions, the smaller the amplitude produced, effectively reducing the risk of harmful vibrations. However, as industrial needs grow more complex, modifications in foundation design, such as incorporating elastic elements like springs, have emerged as viable alternatives. The addition of springs to the foundation can influence the required foundation dimensions, which in turn impacts the GHG emissions produced.

Life Cycle Assessment (LCA) is a widely recognized method for analyzing and evaluating the environmental impacts of a product or infrastructure throughout its entire lifecycle, from raw material extraction, production, use, to final disposal, enabling data-driven decision-making to enhance sustainability (Badan Standarisasi Nasional, 2016). In this study, LCA method is applied to evaluate GHG emissions from the construction of the CO_2 compressor machine foundation at PT Kaltim Methanol Industri. The goal is to identify the lifecycle stages that contribute the most to emissions and determine the type of foundation that is more environmentally friendly.

This research is expected to provide a comprehensive overview of the GHG emissions generated during the construction of the machine foundation. Furthermore, it serves as an initial step in identifying areas that need improvement to reduce the company's carbon footprint. By doing so, PT Kaltim Methanol Industri can make a more significant contribution to global efforts to reduce GHG emissions and achieve more sustainable operations.

Methodology

The methods used in this research include Terzaghi's method for foundation bearing capacity calculations, static and dynamic calculations, and the addition of springs based on Suresh Arya's book (1971), as well as greenhouse gas emission analysis using the Life Cycle Assessment method. Calculations are performed with the assistance of Microsoft Excel and Autodesk Revit applications. The research involves design planning and GHG emission calculations for various types of block foundations, namely standard block foundations, spring block 1, spring block 2, and spring block 3.

The research is conducted at PT Kaltim Methanol Industri, located in Bontang, East Kalimantan. Data collection was conducted from February to June 2024. The research data used in this study consists of two types, primary data and secondary data. Primary data refers to information obtained directly from documents and interviews conducted at PT

Kaltim Methanol Industri, which includes soil data and machine design data. The collected soil data are as follows:

1. Soil type : Sand
2. Internal friction angle (ϕ) : 35°
3. Soil unit weight (γ) : 18 kN/m³

The machine used is a reciprocating compressor with the following specifications:

1. Weight : 70 tons
2. Dimensions : 6 x 10 x 4.5 m
3. Machine speed (f) : 1200 rpm

Secondary data refers to information that has been collected by other parties and is available for reuse in this study. In this research, secondary data is gathered through a literature review, encompassing relevant information on spring specifications and GHG emissions from various sources related to the research topic.

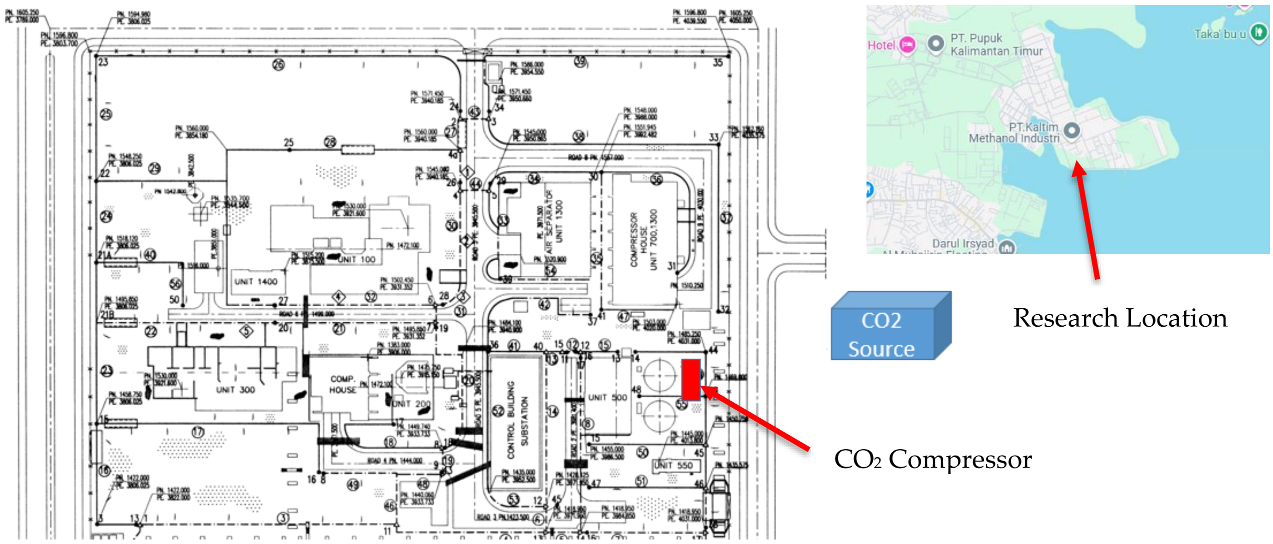


Figure 1. Research Location

The LCA used in this study consists of four stages based on SNI-ISO 14040:2016 issued by the Indonesian National Standardization Agency:

1. Goal and Scope Definition: In this stage, the objectives of the analysis are determined, and the system boundaries are defined. The system boundaries encompass the aspects included in the life cycle to be assessed, such as production, distribution, and disposal stages.
2. Inventory Analysis: This stage involves collecting quantitative data on inputs (such as raw materials, supporting materials, energy, transportation, and tools) and outputs (such as greenhouse gas emissions) from each stage of the life cycle. This data is then used to calculate resource use and the resulting environmental impacts.
3. Impact Assessment: After inventory data has been collected, the environmental impacts of the inputs and outputs are analyzed. This analysis helps to understand the extent to which each stage in the product's life cycle contributes to specific environmental issues.

4. Interpretation: The interpretation stage is used to discuss the results of the impact analysis and identify opportunities for environmental improvement. The researcher draws conclusions and provides recommendations based on the data and analyses conducted.

Result and Discussion

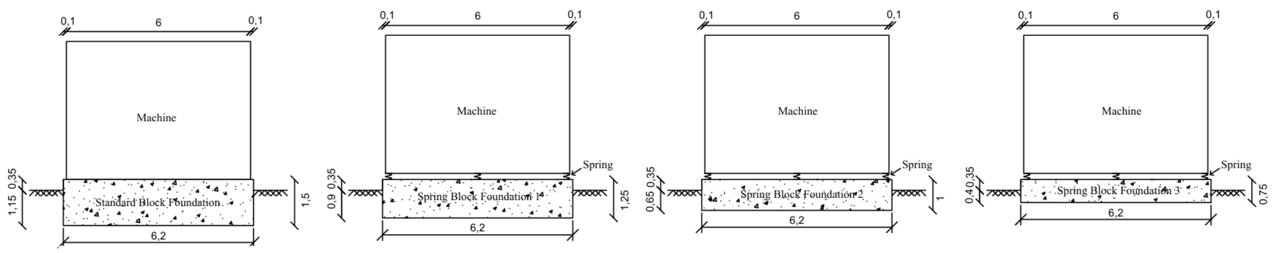
Foundation Design

This research begins with the design of the foundation using the design data in Table 1. The design data has undergone static and dynamic analysis, and has passed the design safety check.

Table 1. Foundation Design Data

Specification	Block Foundation Type			
	Standard	**Spring 1**	**Spring 2**	**Spring 3**
Length (m)	10.2	10.2	10.2	10.2
Width (m)	6.2	6.2	6.2	6.2
Height (m)	1.5	1.25	1	0.75
Embedded Height (m)	1.15	0.9	0.65	0.4
Height from GL (m)	0.35	0.35	0.35	0.35
Max Spring Load (lbs/inch)	-	500	400	300
Number of Springs (unit)	-	10	10	10
Reinforcement (mm)	D25-70	D25-85	D25-105	D25-150

Figure 1 shows the foundation design used in this study



Standard Block Foundation | Spring Block Foundation 1 | Spring Block Foundation 2 | Spring Block Foundation 3

Figure 1. Foundation Design

Raw Material Quantity

Subsequently, the calculation of raw material requirements is carried out by multiplying the concrete volume by the mix design proportions. Concrete volume and reinforcement requirements are obtained from Autodesk Revit.

Table 2. Concrete, Reinforcement, and Springs Required

Block Foundation Type	Concrete (m3)	Reinforcement (kg)	Spring
Standard	92.4810	18,675.1500	-
Spring 1	77.1850	14,640.2500	13
Spring 2	61.7930	11,358.9500	15

Block Foundation Type	Concrete (m3)	Reinforcement (kg)	Spring
Spring 3	46.4570	7,638.0500	15

According to research by Agus Setya Budi (2021), the mix design for 1 m^3 of normal concrete with f'c 30 MPa requires 284.72 kg of cement, 847.2 kg of sand, 924 kg of gravel, and 205 liters of water.

Table 3. Raw Material Requirements

Block Foundation Type	Cement (kg)	Sand (kg)	Gravel (kg)	Water (liters)
Standard	26,331.1903	78,349.9032	85,452.4440	18,958.6050
Spring 1	21,976.1132	65,391.1320	71,318.9400	15,822.9250
Spring 2	17,593.7030	52,351.0296	57,096.7320	12,667.5650
Spring 3	13,227.2370	39,358.3704	42,926.2680	9,523.6850

Raw Material Transportation

The use of fuel in transporting raw materials to the batching plant with transportation equipment results in the release of GHG emissions during the transportation process. In analyzing the resulting GHG emissions, data on the transportation equipment used and its repetition are required. The data is presented in the Table 4.

Table 4. Distance and Raw Material Transporter

Process Unit	Route	Distance to BP (km)	Transporter	Transporter Capacity (t)
Cement Transportation	Land	148	Dump Truck	7.5
Sand Transportation	Land	2.1	Dump Truck	7.5
	Sea	285	Barge	3000
Gravel Transportation	Land	2.1	Dump Truck	7.5
	Sea	285	Barge	3000

The calculation of transportation repetitions for each raw material is performed by dividing the raw material requirement by the transporter's capacity, rounding the result up to the nearest whole number.

Table 5. Raw Material Transportation Repetition

Block Foundation Type	Cement	Sand		Gravel	
	Land	Land	Sea	Land	Sea
Standard	4	11	1	12	1
Spring 1	3	9	1	10	1
Spring 2	3	7	1	8	1
Spring 3	2	6	1	6	1

Production Process

The energy consumption data for the concrete mixing process per m^3 is presented in the table below, which then calculates the total energy consumption for each energy by multiplying the concrete volume by the energy consumption per m^3.

Table 6. Total Energy Consumption of Concrete Mixing

Energy Type	Energy Consumption per m³	Block Foundation Type			
		Standard	Spring 1	Spring 2	Spring 3
Electricity (kWh)	2.9512	272.9299	227.7884	182.3635	137.1039
Natural Gas (MJ)	7.5959	702.4764	586.2895	469.3734	352.8827
Oil (kg)	0.0077	0.7121	0.5943	0.4758	0.3577
Diesel (Gallon)	0.4853	44.8810	37.4579	29.9881	22.5456
Gasolin (Gallon)	0.0026	0.2405	0.2007	0.1607	0.1208
LPG (MJ)	0.9255	85.5912	71.4347	57.1894	42.9960

Material Transportation

The transportation equipment used to deliver fresh concrete and reinforcement materials to the site includes mixer trucks and dump trucks, while cold diesel double (CDD) trucks are used for transporting spring materials.

Table 7. Distance and Material Transporter

Process Unit	Route	Distance to Site (km)	Transporter	Transporter Capacity (t)
Concrete Transportation	Land	2.8	Mixer Truck	6.5
Reinforcement Transportation	Land	238.4	Dump Truck	7.5
	Sea	780.5	General Cargo Ship	33,652
Spring Transportation	Land	261.2	CDD Truck	5
	Sea	780.5	General Cargo Ship	33,652

Transportation repetitions for each material are calculated by dividing the required material quantity by the transport capacity and rounding up to the nearest integer.

Table 8. Material Transportation Repetition

Block Foundation Type	Concrete	Reinforcement		Spring	
	Land	Land	Sea	Land	Sea
Standard	15	3	1	-	-
Spring 1	12	2	1	1	1
Spring 2	10	2	1	1	1
Spring 3	8	2	1	1	1

Usage During Construction

Field concreting work requires several types of equipment, including vibrators, concrete pumps, compressors, and mixer trucks. According to Aurel Sandra Gunawan (2021), spreading concrete with a mixer truck takes approximately 15 minutes for every 12 m^3. The operating time for the vibrator and concrete pump is equivalent to the usage time of the mixer truck, while the compressor requires about 10 minutes for every 100 m^3 of concrete. The duration of equipment usage is calculated by dividing the total concrete requirement by the equipment's capacity, then multiplying the result by the spreading time.

Table 9. Equipment Usage Durations

Block Foundation Type	Mixer Truck (hour)	Vibrator (hour)	Concrete Pump (hour)	Compressor (hour)
Standard	1.9267	1.9267	1.9267	0.1541
Spring 1	1.6080	1.6080	1.6080	0.1286
Spring 2	1.2874	1.2874	1.2874	0.1030
Spring 3	0.9679	0.9679	0.9679	0.0774

Life Cycle Assessment Analysis

The Life Cycle Assessment (LCA) analysis consists of five stages for evaluating greenhouse gas (GHG) emissions. The first stage, "Raw Material," calculates emissions by multiplying the quantity of material used with the total embedded GHG in material. The second stage, "Raw Material Transportation," determines emissions by multiplying the material weight, transportation repetitions, distance, and the emission factor of the transportation equipment. The third stage, "Production Process," evaluates emissions based on energy consumption and the emission factor of the energy source. The fourth stage, "Material Transportation," calculates emissions in the same manner as raw material transportation but focuses on processed materials. Lastly, the fifth stage, "Usage During Construction," computes emissions by considering the number of tools used, their operational time, and the emission factor of the tool.

Table 10. Greenhouse Gas Emissions of Various Block Foundations Types

Stages	Block Foundation Type ($kgCO_2e$)			
	Standard	Spring 1	Spring 2	Spring 3
Raw Material	65,969.8476	53,192.4850	41,870.6139	29,682.8728
Raw Material Transportation	4,856.2352	3,785.6085	3,497.2478	2,437.1085
Production Process	759.3150	633.7272	507.3512	381.4351
Material Transportation	3,911.6059	4,006.6433	3,987.6146	3,967.1902
Use During Construction	162.1472	135.3287	108.3418	81.4532
Total	75,659.1509	61,753.7927	49,971.1693	36,550.0597

Table 10. shows the GHG emissions for each stage and the total GHG emissions generated by various types of block foundations. The stage contributing the most to GHG emissions is the raw material stage. For the standard block foundation, the raw material phase produces the highest GHG emissions at 65,969.8476 $kgCO_2e$, followed by spring block 1 at 53,192.4850 $kgCO_2e$, spring block 2 at 41,870.6139 $kgCO_2e$, and spring block 3 at 29,682.8728 $kgCO_2e$.

In terms of total emissions, the standard block foundation produces the highest GHG emissions at 75,659.1509 $kgCO_2e$, followed by spring block 1 at 61,753.7927 $kgCO_2e$, spring block 2 at 49,971.1693 $kgCO_2e$, and spring block 3 at 36,550.0597 $kgCO_2e$. This reduction in emissions indicates that spring block foundations are significantly more environmentally friendly compared to the standard foundation.

The decrease in emissions is directly related to the reduction in construction material volume for spring block foundations. Smaller foundation dimensions result in lower material requirements, fewer transportation repetitions, reduced energy consumption, and shorter equipment usage durations, which collectively lead to lower GHG emissions. While the addition of springs may slightly increase GHG emissions during the material transportation stage due to the need for additional transport of the springs, the overall environmental benefits of spring block foundations remain substantial.

Overall, spring block foundations offer a significant reduction in total GHG emissions compared to standard block foundations. Among these, spring block 3 stands out as the most sustainable construction option, with the lowest total emissions among all the foundation types analyzed.

Conclusion

Based on the analyzed data, conclusions can be drawn in line with the research objectives. The stage contributing the most to greenhouse gas emissions is the raw material stage. For the standard block foundation, this stage produces the highest greenhouse gas emissions at 65,969.8476 $kgCO_2e$, followed by spring block 1 at 53,192.4850 $kgCO_2e$, spring block 2 at 41,870.6139 $kgCO_2e$, and spring block 3 at 29,682.8728 $kgCO_2e$. Among the foundation types, the spring block foundation, particularly spring block 3, generates the lowest total greenhouse gas emissions at 36,550.0597 $kgCO_2e$.

References

Abdullah, Ahmad Ezat. (2013). Analisa Efisiensi Penggunaan Kapal Tug Boat pada Kapal Tongkang 250 Feet. Universitas Indonesia.

Aini, Oktaviani. (2021). Perencanaan Kapal Tunda (Tug Boat) TB. "Oktaviani" 2 X 425 BHP (Berdasarkan Peraturan BKI 2019). Diploma Thesis, Universitas Diponegoro.

American Petroleum Institute. (2009). API 686 Recommended Practices for Machinery Installation and Installation Design, PIP REIE 686, Second Edition 2009.

Arrasyidi, Addina Salam. (2022). Pengaruh Dimensi Pondasi dan Kapasitas Mesin terhadap Respon Statis dan Respon Dinamis Pondasi Mesin Jenis Blok (Kasus: Desa Ngentep, Kabupaten Magetan). Universitas Sebelas Maret, Surakarta.

Arya, S, O'Neill, M, dan Pincus, G. (1979). Design of Structures & Foundations for Vibrating Machines. Gulf Publishing Company, Houston, London, Paris, Tokyo.

Badan Standarisasi Nasional. (2002). SNI 03-2847-2002 Tata Cara Perhitungan Struktur Beton untuk Bangunan Gedung. Bandung: Badan Standarisasi Nasional.

Badan Standarisasi Nasional. (2006). SNI ISO 14040:2006 Manajemen Lingkungan - Penilaian Daur Hidup - Prinsip dan Kerangka Kerja. Bandung: Badan Standarisasi Nasional.

Budi, A. S., Safitri, E., Kuncoro, F. B. (2021). Kajian Kuat Tekan, Kuat Tarik Belah, dan Modulus Elastisitas Beton dengan Bahan Pengganti Semen Fly Ash Kadar 15%, 30%, dan 40% terhadap Beton Normal. Jurnal Matriks Teknik Sipil Vol 9, No 3.

Direktorat Jenderal Bina Marga. (2010). Spesifikasi Umum Edisi 2010 Revisi 2. Jakarta: Kementerian Pekerjaan Umum Direktorat Jenderal Bina Marga.

Direktorat Jenderal Cipta Karya. (1971). Peraturan Beton Bertulang Indonesia (PBI 1971). Jakarta: Departemen Pekerjaan Umum.

Dirjen Pengendalian Pencemaran dan Kerusakan Lingkungan. (2021). Pedoman Penyusunan Laporan Penilaian Daur Hidup (LCA) Edisi Pertama, September 2021. Jakarta: Direktorat Jenderal Pengendalian Pencemaran dan Kerusakan Lingkungan, Kementerian Lingkungan Hidup dan Kehutanan RI.

Ecochain. (2024). Cradle to Grave in LCA – What is it & How does it work?. https://ecochain.com/.

Ghofar, M. (2023). Semen Produksi Kaltim Mampu Penuhi Kebutuhan IKN. Antaranews. https://www.antaranews.com/berita/3693564/semen-produksi-kaltim-mampu-penuhi-kebutuhan-ikn.

Gunawan, Hendry. (2017). Pengaruh Kedalaman, Tinggi Pondasi Mesin Jenis Blok dan Jenis Tanah Terhadap Amplitudo. Universitas Sebelas Maret, Surakarta.

Gunawan, Aurel Sandra. (2021). Analisis Emisi Gas Rumah Kaca pada Pekerjaan Beton Konstruksi Spillway Bendungan Tugu dengan Metode LCA. Universitas Sebelas Maret, Surakarta.

Hakam, Abdul. (2008). Rekayasa Pondasi. Padang: CV. Ferila.

Handayani, F. S., Pramesti, F.P., Wibowo, A.W., Setyawan, A. (2019). Estimating and Reducing the Release of Greenhouse Gases in Local Road Pavement Constructions. International Journal on Advanced Science Engineering Information Technology Vol.9 No.5.

Kuncara, Febryan Mulya. (2018). Evaluasi Emisi Gas Rumah Kaca pada Tahap Pekerjaan Beton High Volume Fly Ash-Self Compacting Concrete Konstruksi Rumah Dua Lantai dengan Metode Life Cycle Analysis. Universitas Sebelas Maret, Surakarta.

Nasution, D. D., dan Christiyaningsih. (2022). Pupuk Kaltim Olah 35 Ribu Ton Limbah Batu Bara Jadi Bahan Bangunan. Republika. https://ekonomi.republika.co.id/berita/rfiw8k459/pupuk-kaltim-olah-35-ribu-ton-limbah-batu-bara-jadi-bahan-bangunan.

Pusdiklat Jalan, Perumahan, Permukimman, dan Pengembangan Infrastruktur Wilayah. (2017). Modul 4 – Produksi dan Pengangkutan Campuran Beton. Bandung: Kementerian Pekerjaan Umum Dan Perumahan Rakyat.

Redaksi. (2018). PT KIE dan PT HTT Hanya Miliki Stok 3000 Kubik Pasir dan Koral. Beritakaltim. https://beritakaltim.co/2018/11/08/pt-kie-dan-pt-htt-hanya-miliki-stok-3000-kubik-pasir-dan-koral/.

Sandi, Ferry. (2023). Ternyata Besi sampai Pasir Proyek IKN Didatangkan dari Sini. CNBC Indonesia. https://www.cnbcindonesia.com/news/20230526171059-4-440982/ternyata-besi-sampai-pasir-proyek-ikn-didatangkan-dari-sini.

Sipil, T. P. (2024). Buku Panduan Penulisan, Tata Laksana dan Ujian Akademik Tugas Akhir/Skripsi serta Magang (KKM)/KP. Surakarta: Prodi Teknik Sipil.

Syahidi, Shofa. (2017). Pengaruh Luas Penampang Pondasi Mesin Jenis Blok dan Parameter Tanah Berbutir Halus terhadap Amplitudo. Universitas Sebelas Maret, Surakarta.

United Nations Environment Programme. (2021). 2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi. www.globalabc.org.

Wijayanto, Alif Kurnia. (2022). Analisis Emisi GRK dengan Metode LCA pada Pekerjaan Konstruksi Jembatan Simpang Susun Rangkasbitung. Universitas Sebelas Maret, Surakarta.