ENGINEERING ANALYSIS IMPACT ON CARBON EMISSION REDUCTION OF AN INFRASTRUCTURE PROJECT: A CASE STUDY OF SEMANTOK DAM PROJECT

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ABSTRACT: *Semantok Dam located in Semantok River Stream, Nganjuk District, East Java. Dominated by lowlands and mountains, the 1900-hectare fertile agricultural land will be irrigated by this nominated "The Longest Dam in Southeast Asia". The construction of this three kilometers long dam requires enormous resources of rockfills as the dominant material to build the main dam body. While the process of excavation, mobilization, and material settings are the dominant contributor aspects of the project's carbon footprint, at the same time this project encounter a challenge on insufficiency of existing quarry. This situation drives a comprehensive strategy not only to find the most efficient and accessible material, but also to minimize and mitigate environmental damage, ultimately by reducing the material carbon footprint. Thus, an innovative engineering solution is applied to overcome this challenge such as utilizing the available material in surrounding project site which is random rock soil by using geotechnical analysis tools for design optimization and material usage simulation also collaborating with Building Information Modeling (BIM) to visualize and calculate the estimated cost. Eventually, this analysis plays a big role in ensuring the environmental sustainability in an infrastructure project by deciding the appropriate alternative which produce the least carbon emission.*

KEYWORDS: *BIM, Carbon Footprint, Engineering Analysis, Resource Management, Sustainability*

1. INTRODUCTION

Embodied carbon represents the million tons of carbon emissions released during the lifecycle of infrastructure building materials; including extraction, manufacturing, transport, construction, and disposal. Concrete, steel, and insulation are all examples of materials that contribute to embodied carbon emissions [1]. Furthermore, other activities like excavating and earthmoving materials like rocks, soil, sand, and other similar substances can also significantly contribute to embodied carbon emissions especially when used in large volumes. The buildings and construction sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO_2) emissions in 2018 [2]. Global buildings and construction sector emissions increased 2% from 2017 to 2018, to reach a record high, while final energy demand rose 1% from 2017 and 7% from 2010. Increases were driven by strong floor area and population expansions [2].

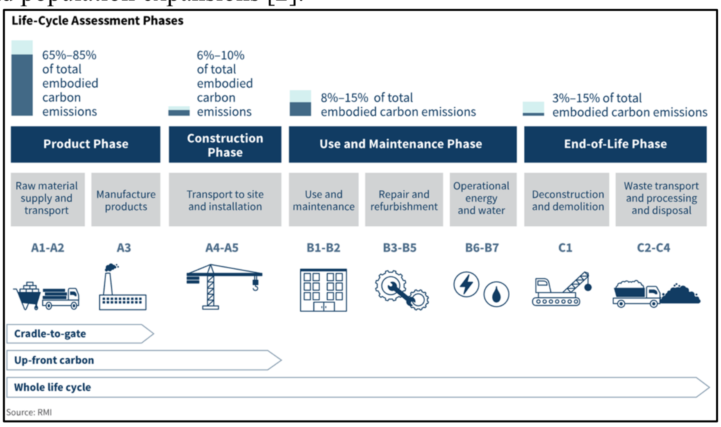

Fig. 1: Life-Cycle Assessment Phases of Embodied Carbon Emission in General Building
Source: RMI

While infrastructure buildings sector efficiency improvements continued to be made, they were not adequate to outpace demand growth. 2020 is a key year for countries to enhance their Nationally Determined Contributions (NDCs), especially concerning further actions to address energy use and emissions including embodied emissions in the buildings and construction sector [2]. Countries are innovating and implementing measures to improve efficiency and reduce emissions from their building stock. As sharing effective measures globally would amplify

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their impact, regional roadmaps are being developed for this purpose [2].

Indonesia seriously and consistently continues to conduct its commitment to address climate change through Low Carbon Development Planning (PPRK) [3]. PPRK is a strategic transformation of the National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GRK) program as stipulated in Presidential Regulation No.61 Year 2011 [3]. As a form of consistency in efforts to address climate change, the issue is one of the national priorities that becomes a cross-cutting program in the 2015-2019 National Medium-Term Development Plan (RPJMN) document. President Joko Widodo has delivered a commitment at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015, which is to reduce emissions by 29% (Fair scenario / using own capabilities) and by 41% (ambitious scenario / if you get international support) [3]. The commitment was ratified through Law No.16/2016 on the Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change [3]. Aligning with these commitments, Indonesia's efforts directly support the objectives of the United Nations Sustainable Development Goals (SDGs), specifically SDG 13, which is "Climate Action." By focusing on Low Carbon Development Planning and reducing greenhouse gas emissions. By synchronizing its national strategies with global sustainability targets, Indonesia not only demonstrates its dedication to combatting climate change domestically but also champions a collective global responsibility.

Carbon emissions mitigation in the construction sector is not easy. The adoption of digital construction technologies emerges as a potent strategy to mitigate carbon emissions in the construction sector. Leveraging digitalization allows architects, engineers, and stakeholders to collaboratively refine building designs, emphasizing energy efficiency. Energy efficiency could be achieved through several things, such as insulation, natural lighting, and heating and cooling systems, effectively diminishing a building's carbon output over its entire lifecycle. Digital engineering improvements such as reducing waste and promoting the selection of materials through good planning can reduce carbon footprints. Hence, embracing digitalization not only signifies technological progression but also propels industry towards the broader objective of environmentally sustainable construction and reduced carbon emissions.

2. BACKGROUND OF STUDY

The construction industry is faced with challenges such as project delays, over budget costs, quality issues, and environmental concerns. Digital construction technologies such as engineering analysis, digital survey tools, Building Information Modelling (BIM), and Geographic Information System (GIS) are proposed as a solution to these problems. The integration of those technologies plays a big role in optimizing productivity in project construction and to ensure engineering validation accuracy. The data which was given by the planning consultant will be validated so it can be executed on the field. Initial mapping is processed using digital survey tools. The mapping results are used as a basis for the BIM reality model to aid the design team gain a better understanding of the project's characteristics. Furthermore, the use of BIM enables real-time monitoring and simulating through the entire building life cycle process. GIS is utilized to enhance decision-making for continued management monitoring, reducing all risks that could arise throughout the project execution phases.

According to the Indonesian Public Works and Housing Ministry's Regulation No. 9 of 2021 on sustainable development guidelines, the implementation of BIM is mandatory. BIM facilitates the visualization of plans and their execution, ensuring a consistent interpretation amongst all stakeholders, thereby minimizing the potential for errors or misunderstandings. Although the design process is usually established at the beginning there are often real project conditions that do not match the initial design, which triggers design changes. BIM plays a crucial role in speeding up the analysis of these design alterations. With the acceleration of this decision-making process, BIM also contributes to cost and time efficiency.

Besides all the benefits that can be provided by BIM tools, to boost the impact on calculating carbon emissions on a construction project, the data produced by BIM should be integrated with comprehensive analytical calculations to ensure the carbon footprint is determined in a scientifically accurate way.

Completely eliminating carbon emissions in a project may not be an option, but the project management can control and minimize these emissions through responsible selection of materials, designs and working methods. Before making these choices, it is important to assess the impact of each option. Thus, the most effective options can be selected and implemented in the field.

This study aims to compare the embodied carbon contained in the initial design of an infrastructure project and the alternate design after validating the latest situation on the project site. The necessity for this comparison arises from differences in the field conditions, particularly the availability of materials, which did not align with the conditions assumed in the initial design.

3. PROJECT OVERVIEW

The Semantok Dam Project is one of the National Strategic Projects in Indonesia, located in the Semantok River Stream, Nganjuk District, 115 km West of the Surabaya City, East Java. The Semantok Dam's primary objectives are to lessen flood discharge and assure water availability on its coverage area during both the rainy and dry seasons due to the intense annual rainfall. The terrain of the Nganjuk district is dominated by the lowlands and the mountains, making the soil condition fertile for cultivating plants. Semantok Dam will irrigate the 1900-hectare coverage agricultural area in Nganjuk District where its existence expected to boost agricultural productivity from 186.33% to 300%. Moreover, the presence of this dam will be the new tourism destination in East Java Province.

The construction cost of this project reaches 87.9 million USD covering dewatering process, main dam, spillway, intake channel, facility building, geotechnical and hydromechanical works. With the total main dam’s length of 3.1 km and height of 31.56 m, Semantok Dam is claimed as “The Longest Dam in Southeast Asia”. The total capacity of the main dam is approximately 33 million m^3. The length of Semantok’s spillway is 62.69 m with overflow discharge of 574.54 m^3/second. While the length of the dam’s intake is 16.38 m with the tower dimension of 1.75 x 1.75 m using reinforced concrete.

According to the initial design, rockfills were used as the primary material for the dam. However, the rockfills quantity was insufficient in the existing quarry. Therefore, two alternatives were solving the problems. Firstly, choosing a new quarry where rockfills are available, but it would drive a significant cost addition and wellness issue for the surrounding society. Secondly, using the available materials in the existing quarry, which was random soil. Considering the environmental matters, Hutama Karya, as the lead contractor, validated the cost, time, and environmental implications and preferred to use random soil as the primary materials. However, a slope redesign was required, as the strength of random soil was below that of the rockfills.

4. JUSTIFICATION DESIGN

Before the construction of the dam began, Hutama Karya as the lead contractor initiated an advanced design study to ensure the feasibility of the initial design, which would then be adapted based on current field conditions. This study included a preliminary geological investigation of the construction site and a review of the dam body's zoning design, adjusted for the availability of fill materials. The consultant engineers initially developed a grouting system as the foundation for the main part of dam, however, Hutama Karya discovered the brittle and loose sandy soil layer would cause persistent water leaks over the maximum amount permitted. Hutama Karyaneeded to undertake soil analysis to determine alternative design methods and ensure the dam would be strong enough to contain water from intense rains without flooding. The results from the initial geological investigation of the construction location differed from the initial planning design, necessitating further studies into the dam foundation repair plan.

The Bendoasri and Teritik Quarry are still on the planning stage. In the initial design provided by the consultant engineers, the zoning of the dam body is an upright core type with rockfill. However, based on the results of the initial geological investigation on construction phase, the two quarries did not have sufficient stone material available. The quantity/volume of stone material availability was quite limited, on contrary random soil material was abundant. The plan became difficult to accomplish, as the nearby quarry could not produce enough rock for the long dam without deep damaging excavation. Another option is digging a new quarry for the site, but that would be costly.

The insufficiency of rockfills in the existing quarry is one of the biggest matters in the Semantok Dam Project. Due to environmental and material availability considerations, the project team replaced the rockfills with random soils – available material in the fields. However, the random soil strength was below the rockfills. The insufficiency of rock created risk to potentially redesigning the dam slope. Engineering analysis software was utilized to model the material replacement and verify whether the initial slope design was still applicable in the fields.

In the beginning, Hutama Karya tried to model the random soil in the initial design and found that the safety factor of the slope (1.183) was below the minimum requirements (1.302) and showing that the slope was inapplicable. Thus, with engineering analysis software, a process of trial and error was undertaken to find the safest and most optimized design. As a result, the assessment indicated that the slope should have a steeper incline of 1:3 on the left side and 1:2.75 on the right side to produce the safety factor of 1.644, which fulfilled the minimum requirements. Not only did solve the problems, but also able to gain more value in terms of materials and method efficiently. Hutama Karya was able to avoid 1.8 million USD of reworking by renewing the slope design.

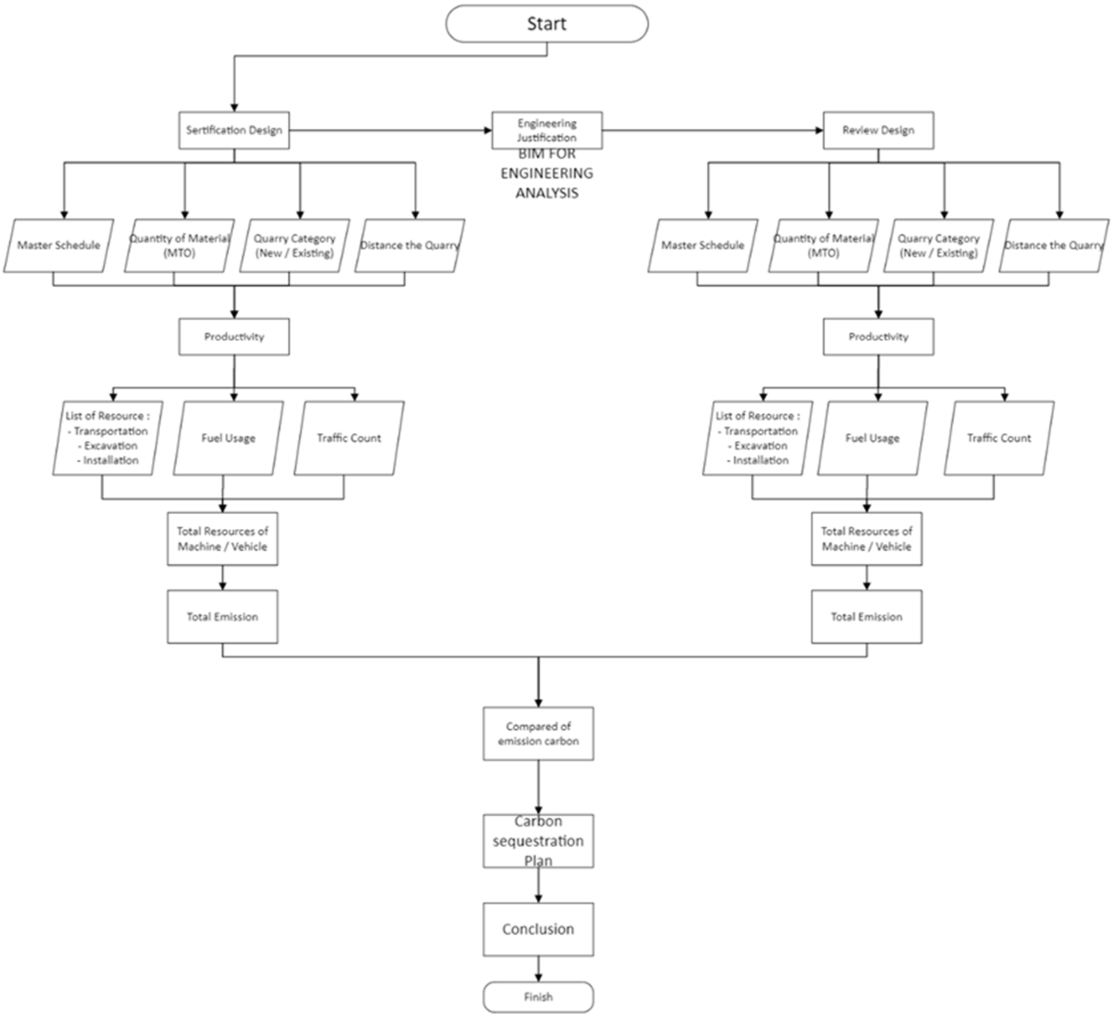

Fig. 2: Calculation Flow

5. LIMITATION OF STUDY

This study will focus on emphasizing the calculation of the carbon footprint arising from design changes because of engineering justification using Building Information Modelling (BIM) & engineering analysis software. In this context, the case that becomes the focus point is the change in the selection of the main material used in the construction of the dam body.

This process of calculating the carbon footprint does not cover all aspects of construction, but rather focuses on some essential elements that are directly affected by changes in design. These aspects include the creation of a new quarry which is the main source of construction materials, the distance of material delivery from the quarry to the construction site, the number and type of equipment used in material delivery and the construction process itself.

Therefore, this study aims to provide a clear and comprehensive picture of how design changes using BIM and engineering analysis software can affect the carbon footprint in construction projects and provide a foundation for more informed and sustainable decision-making.

6. CALCULATION METHODS

This Figure shows the flow of study methods.

In this study, as illustrated in Figure 2, the calculation method involves comparing two distinct scenarios. In the first scenario, we consider the initial design or Design Certification, which upon implementation, has been found lacking in terms of material sufficiency. The available quarry is incapable of providing the necessary quantity of materials, leading to the need for another quarry that is considerably distant from the project site.

The second scenario maintains the usage of the first quarry that planned available material, in proximity to the project site but demands alterations in the design, necessitating recalculations and technical justifications. The changes are to ensure that the local materials meet the specifications required for dam construction. But the first quarry was originally a pine forest area, so the utilization of the quarry will require land conversion, also calculate how much carbon stock is lost and how many trees were cut down to facilitate reforestation after construction finished.

Data is collected for both scenarios, including the quantity of materials needed per the initial and revised designs, the dam project completion schedule, and the distance between the quarry and the project site. From these data, we can establish productivity targets for the work, thus enabling the detection of resource requirements.

After determining the necessary equipment, the next step is to calculate fuel consumption during the construction process for each heavy equipment used. Once the total fuel used is determined, this amount is then converted to a form of energy. Energy conversion from the use of diesel fuel to other forms of energy is an average of 38.243 MJ/Liter or 38.243 x 10^-6 TJ/Liter. After being converted to a form of energy (TJ), the next step is to calculate the resulting carbon emissions. To calculate this, we use a formula derived from the IPCC Guidelines for National Greenhouse Gas Inventories (2006).

$$Emission = \sum_{j}^{n} \left(Fuel_j \times EF_j\right) \quad \text{.......................................} (1)$$

Where:

Emission = Total of Emission (Kg)

Fuel = Fuel Consumed (TJ)

EF = Emission Factor (Kg/TJ)

j = Fuel Type

For the type of fuel, all heavy equipment used uses diesel oil. The emission factor for the type of diesel oil fuel is 74,100 Kg/TJ, as shown in Table 1.

Table 1: Road Transport Default CO_2 Emissions Factors and Uncertainty Ranges

Fuel Type	Default (Kg/TJ)	Lower	Upper
Motor Gasoline	69300	67500	73000
Gas / Diesel Oil	**74100**	**72600**	**74800**
Liquefied Petroleum Gases	63100	61600	65600
Kerosene	71900	70800	73700
Lubricants	73300	71900	75200
Compressed Natural Gas	56100	54300	58300
Liquefied Natural Gases	56100	54300	58300

Source: IPCC Guidelines for National Greenhouse Gas Inventories (2006)

Subsequently, these results are utilized to calculate the carbon emission resulting from each scenario. Finally, the data from both scenarios is compared to draw insightful conclusions then plan to replace the carbon lost due to land conversion.

7. DATA COLLECTION

As initial information, to find out the body parts of the dam, below is a typical picture of the cross section of the dam building structure.

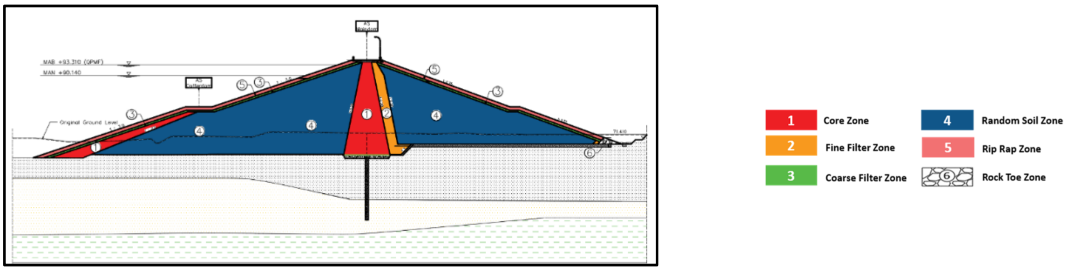

Fig. 3: Typical Cross Section of Dam

The insufficient material is in the Zone 4, which is the most dominant part of the entire dam structure, comprising 67% of the total volume of the dam. According to the master schedule and contract, the work on the zone four must be completed within 24 months or 730 Days to avoid disrupting subsequent tasks. The quarry has two alternative locations. The first quarry is in the Bendo Asri & Tritik area, but it does not contain rock soil materials that passed the required specifications. The second quarry is in the Blitar & Kediri area and the rock soil materials there passed the required specifications. Figure 4 shows the distance between the project's site to each quarry. The distance to the first quarry is approximately 10.5 Km and the distance to the second quarry is approximately 84.6 Km.

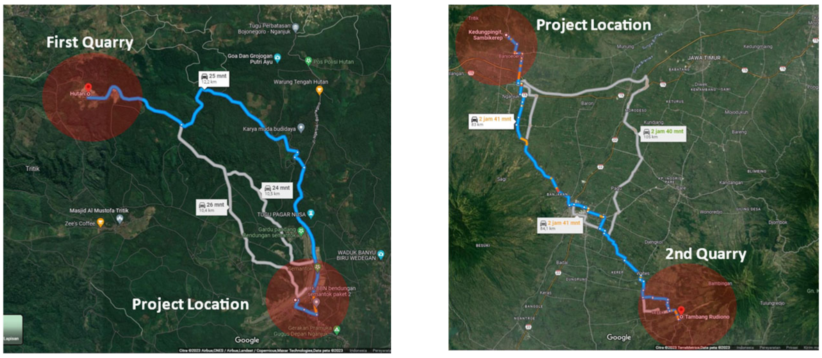

Fig. 4: Distance Between First Quarry (Bendoasri & Tritik) and Second Quarry (Kediri & Blitar) with The Project

The result of the assessment on the potential quarry sites shows that the first quarry is in an area originally covered by a pine forest. Utilizing this site would convert the landscape of the surrounding area from forest to quarry. The second quarry, for comparison, is a pre-existing site so there is no additional land conversion would be required for it to be operational, but it has downside which is the distance between the quarry and the project's site.

7.1. Initial design / design certification

This project's initial design stage is also known as the design certification. At this stage, the initial design specifies Rockfills material for the zone four of dam's body. The material shall be obtained from quarry sources in the Bendoasri and Tritik localities, approximately ten kilometers from the project site, as shown in Figure 4. Based on Table 2, the initial design data indicates that rockfill material can be sourced from the Bendo Asri & Tritik quarry, ensuring sufficient supply.

Table 2: Initial Condition Based on Design Certification

Material	Before Soil Investigation					
	Volume required (m^3)	Volume Quarry (m^3)	Location	Distance (KM)	Ratio	Availability
Rockfills	1,998,934	2,390,000	Bendo Asri &Tritik	10	1.20	Fulfilled

Upon further soil investigation in the pre-construction phase, it was found that the quarry did not contain rockfill material that met the initial design specifications, rendering it unsuitable as a rockfill quarry. To address this issue, an alternative location was sought that contained rockfill material meeting the specifications. A suitable quarry was found in the second quarry at the Kediri and Blitar areas, approximately 85 KM away, as illustrated in Figure 4. Therefore, Case A involves replacing the original quarry with the second quarry, which contains suitable rockfill material. This switch leads to changes in the data, as depicted in Table 3.

Table 3: Initial Condition Based on Design Certification After Change to Second Quarry

Material	Alternative Quarry After Soil Investigation					
	Volume required (m^3)	Volume Quarry (m^3)	Location	Distance (KM)	Ratio	Availability
Rockfills	1,998,934	3,107,000	Kediri & Blitar	85	1.55	Fulfilled

7.2. Design change / design review

Following the soil investigation, it was discovered that most of the material at the original quarry located in Bendo Asri & Tritik, is random soil. To prevent relocating the quarry, a design review was conducted, which involved changing the dam body material from rockfills to random soil. Hutama karya determined that the design issues can be solve by using reality modeling and geotechnical design.

First, a laser scanner undertook at the project area, created point clouds, and molded them into a digital replica of the site by using Context Capture Software. The digital replica helped the project team understand the existing condition of the field and plan local quarry locations, minimizing the excavation depth to limit the impact on the environment. The team then imported reality modeling data into their bespoke project management information system, giving the project manager insight into real-time conditions. Next, the organization then augmented the reality model with geotechnical analysis via Plaxis Software, enabling them to simulate foundation options and test the groundwater flow. Plaxis enabled them to model soil fill within the proposed dam design and test its performance within the area's terrain. Though the initial slope design did not meet safety requirements, they used OpenRoads Designer Software to evaluate other slope designs, eventually realizing that a greater slope on the left side of 1:3 combined with a lesser slope of 1:2.75 on the right side would meet safety requirements for both construction and operations while incorporating the sandy soil as fill. This adjustment will increase the safety factor and strength, leading to an expansion in the volume of the dam body in Zone 4. Accordingly, fortification calculations were conducted using the Plaxis and OpenRoads Designer Software, as shown in Figure 5.

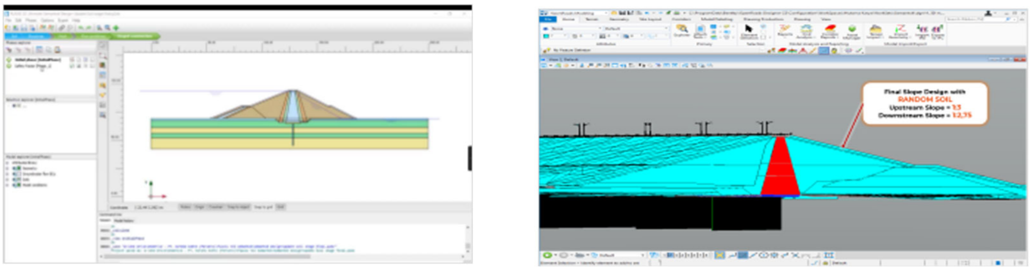

Fig. 5: Redesign Calculation of the Dam Body Using Plaxis and OpenRoads Designer Software

Lastly, to ensure the changes to the design would not impact the tight deadline, Hutama Karya simulated the construction with Synchro Software. In addition to testing the construction feasibility of the new design, the application helped them plan the construction process.

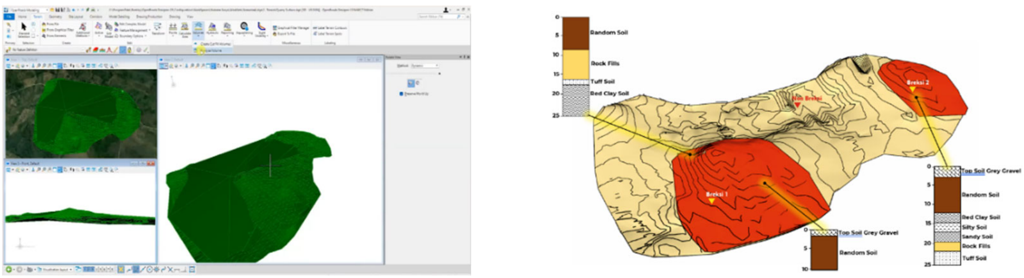

Fig. 6: Quarry BendoAsri & Tritik Classification & Quantification Using OpenRoad Designer

As shown in Figure 6, to ensure the availability of the quarry in that area, the quarry volume was recalculated using BIM to speed up the quantification process. Material take off generated from a 3d model created in OpenRoad Designer Software to help the engineers accurately visualize upon calculation, it was estimated that there is 5.3 million cubic meters of random soil available. Therefore, the first quarry is still utilized, but changes are made to the dam body design so that random soil material can still be used, as indicated in Table 4.

Table 4: Condition After Design Review Using the Random Soil Material at First Quarry

Material	Random Soil in First Quarry after Design Review					
	Volume required (m^3)	Volume Quarry (m^3)	Location	Distance (KM)	Ratio	Availability
Random Soil	2,308,176	5,326,000	Bendo Asri &Tritik	10	2.31	Fulfilled

The first quarry is currently a pine forest owned by Perhutani. When this pine forest is converted into a quarry location, the carbon stock will disappear. Therefore, to comply with existing regulations and to support sustainable project achievement towards the SDGs, Hutama Karya, as the contractor, is obliged to replace the carbon at the quarry site by reforesting after the project is completed and the quarry is no longer in use.

Table 5: calculation of the amount of carbon lost from land conversion.

Area Quarry (m^2)	Area Quarry (Ha)	Type of Tree	Amount of Tree	Carbon of each tree (KgCo₂/Pine)	Total Amount of Carbon (KgCO₂)	Total Amount of Carbon (TonCO₂)
200,000	20	Mercus Pine	141,541	22.60	3,198,827	3,199

According to the data in Table 5, it turns out that by converting a 20-hectare pine forest, a carbon reserve of 3,200 tons of CO_2 will be lost. This loss will be offset by reforestation after the project is completed.

8. DATA PROCESSING

The data calculation begins with the collection of initial data, followed by determining the productivity targets for each case based on the distance and travel time to the quarry, as well as the execution time (work schedule and working hours). The results of these calculations can be seen in Table 6.

Table 6: Comparison Resume of Initial Data & Target Productivity each Case

No	LIST	CASE A		CASE B	
1	Materials	Rockfills		Random Soil	
2	Volume required (m^3)	1,998,934	m^3	2,308,176	m^3
3	Volume Quarry (m^3)	3,107,000	m^3	5,326,000	m^3
4	Location Quarry	Kediri & Blitar		Bendo Asri &Tritik	
5	Ratio Stock Quarry	1.55		2.31	
6	Availability	Fulfilled		Fulfilled	
7	Quarry Type	Existing Quarry		New Quarry	
8	Distance From Project (KM)	85	KM	11	KM
9	Duration Quarry - Project (Minute)	160	Minute	25	Minute
10	Work Hour in a Day	8	Hour	8	Hour
11	Schedule Duration of Work	730	Days	730	Days
12	Target Productivity/day	2,738	m^3/day	3,162	m^3/day

After determining the productivity targets, the next step is to ascertain the equipment needs for each case. To simplify this process, equipment needs are determined for three different locations: the equipment located at the quarry site, the equipment used for construction processes, and the equipment needed for transportation processes.

As seen in Tables 7, 8, and 9, these illustrate the heavy equipment requirements for Case A, calculated based on the work's productivity targets, along with an estimate of fuel consumption for each location.

Table 7: Equipment Requirements & Fuel Consumption at the Quarry Location (Case A)

Equipment	Type	Unit	Fuel Type	Consumption/ Hour/ Machine	Work Hour	Project Duration (Days)	Fuel Consumption		Total Consumption
							(liter/h)	(Liter/ day)	
Excavator 01	Operational Weight 20T	3	Diesel	14	8	730	42	336	245,280
Excavator 02	Operational Weight 30T	1	Diesel	20	8	730	20	160	116,800
Excavator 03	Operational Weight 50T	1	Diesel	40	8	730	40	320	233,600
Excavator 04	Breaker	6	Diesel	25	8	730	150	1200	876,000
TOTAL CONSUMPTION (Liter)									1,471,680

Table 8: Equipment Requirements & Fuel Consumption at the Main Dam Location (Case A)

Equipment	Type	Unit	Fuel Type	Consumption/ Hour/Machine	Work Hour	Project Duration (Days)	Fuel Consumption		Total Consumption
							(liter/h)	(Liter/day)	
Bulldozer	D85SS	5	Diesel	22	8	730	110	880	642,400

VibroSmooth	SD 110	5	Diesel	18	8	730	90	720	525,600
VibroPadfoot	SD 110	5	Diesel	19	8	730	95	760	554,800
TOTAL CONSUMPTION (Liter)									**1,722,800**

Table 9: Equipment Requirements & Fuel Consumption of the Transportation (Case A)

Equipment	Type	Unit	Fuel Type	Travel Speed (KM/h)	Average Consumption		Mileage (Km)	Trip/ DT	Project Duration (Days)	Total Consumption
					(liter/h)	(liter/km)				
DumpTruck	Capacity 30T	72	Diesel	30	50	1.67	84.5	2.3 Times	730	17,025,060
TOTAL CONSUMPTION (Liter)										**17,025,060**

Based on the data above, the total fuel consumption for Case A is 20,219,540 liters.

Next, the calculation of heavy equipment requirements and fuel consumption on Case B, calculated based on productivity targets, can be seen in Tables 10, 11, and 12.

Table 10: Equipment Requirements & Fuel Consumption at the Quarry Location (Case B)

Equipment	Type	Unit	Fuel Type	Consumption / Hour / Machine	Work Hour	Project Duration (Days)	Fuel Consumption		Total Consumption
							(litre/h)	(Litre/ day)	
Excavator 01	Operational Weight 20T	3	Diesel	14	8	730	42	336	245,280
Excavator 02	Operational Weight 30T	1	Diesel	20	8	730	20	160	116,800
Excavator 03	Operational Weight 50T	1	Diesel	40	8	730	40	320	233,600
Excavator 04	Breaker	4	Diesel	25	8	730	100	800	584,000
TOTAL CONSUMPTION (Liter)									**1,179,680**

Table 11: Equipment Requirements & Fuel Consumption at the Main Dam Location (Case B)

Equipment	Type	Unit	Fuel Type	Consumption/ Hour/Machine	Work Hour	Project Duration (Days)	Fuel Consumption		Total Consumption
							(litre/h)	(Litre/day)	
Bulldozer	D85SS	4	Diesel	22	8	730	88	704	513,920
VibroSmooth	SD 110	4	Diesel	18	8	730	72	576	420,480
VibroPadfoot	SD 110	4	Diesel	19	8	730	76	608	443,840
TOTAL CONSUMPTION (Liter)									**1,378,240**

Table 12: Equipment Requirements & Fuel Consumption of the Transportation (Case B)

Equipment	Type	Unit	Fuel Type	Travel Speed (KM/h)	Average Consumption		Mileage (Km)	TRIP / DT	Duration Project (Days)	Total Consumption
					(litre/h)	(litre/km)				
DumpTruck	Capacity 30T	62	Diesel	30	50	1.67	10.5	6 Times	730	4,752,300
TOTAL CONSUMPTION (Liter)										**4,752,300**

Based on the data on Table 10, Table 11 and Table 12, the total fuel consumption for Case B is 7,310,220 liters.

After calculating the total equipment and fuel needs for Case A and Case B, the next step is to convert the total fuel consumption into energy (TJ). This is done by multiplying the total fuel consumption requirements by the specific heat of diesel fuel. The results of these calculations can be seen in Table 13.

Table 13: Conversion the Consumption of Fuel (Liter) to the Consumption of Energy (TJ)

Energy Conversion Calculation	CASE A		CASE B	
Consumption (Litre)	20,219,540	Litre	7,310,220	Litre
Calor Specific (TJ/Litre)	0.000038243	TJ/Litre	0.000038243	TJ/Litre
Consumption (TJ)	**773.255868220**	**TJ**	**279.564743460**	**TJ**

Once all the necessary data is available, the next step is to calculate the carbon emissions generated from each case using the emissions formula (1). The efficiency factor of CO_2 for diesel type is approximately 74,100 (Kg/TJ). The results of the comparison can be seen in Table 14. The table shows that in Case A, there is no additional carbon emission from land conversion, whereas in Case B, the carbon emission is increased due to the land being converted from a pine forest to a quarry. Therefore, the total emissions generated from Case A and Case B are 57,298 Ton and 23,914 Ton respectively. This results in a difference in emissions between the two cases of 33,383.69 Ton.

As a result, Hutama Karya, the main contractor, has chosen Case B, which contains lower carbon emissions than Case A. In response, Hutama Karya will also implement a carbon recovery plan by reforesting a 20-hectare area at the Bendoasri and Tritik quarry sites. This initiative is taken to support the Sustainability Development Goals

13 Climate Action.

Table 14: Emission Carbon Calculation

Emission Calculation	CASE A		CASE B	
Consumption (TJ)	773.255868220	TJ	279.564743460	TJ
EF CO_2 Diesel	74100	(kg/TJ)	74100	(kg/TJ)
Emission (Kg)	57,298,260	Kg	20,715,747	Kg
Emission (Ton)	57,298.26	Ton	20,715.75	Ton
Emission From Land Use Change				
Pine Mercussi to Quarry	-	Ton	3,198.83	Ton
Total Emission	**57,298**	**Ton**	**23,914.57**	**Ton**

9. CARBON RECOVERY PLAN & SUSTAINABLE CONSTRUCTION

Hutama Karya, in its commitment to sustainable development, plays a significant role as a contractor in the construction of the Semantok Dam. As part of their responsibilities, they have implemented reforestation initiatives in response to the conversion of the quarry land. Hutama Karya has planted over 2,000 trees on the former quarry site and an additional 6,000 trees in the surrounding dam area. Additionally, they have planted Vetiver Grass to stabilize the slopes of the spoil bank, which is made of excavation waste material. The project was completed in 2022, and Reforestation efforts continue periodically even today.

Fig. 7: Iriana Joko Widodo, The First Lady, planted date palm trees as a symbol of environmental awareness (Left Side), tree planting and fish hatchling activities by Central & Local Government (Right Side)

In figure 7 (on the left side) during the inauguration of the Semantok Dam, Iriana Joko Widodo planted date palm trees as a symbol of environmental awareness. On the right side of Figure 7, enthusiasm for reforestation also received support from both the central and local governments, who have participated in tree planting and fish hatchling releases into the dam. These efforts are part of a recovery plan intended to replace the lost carbon reserves and support SDG number 15: Life on Land, as Carbon recovery plans often involve afforestation and reforestation initiatives, which help restore land and create wildlife habitats.

The reforestation activities may not be enough to replace the lost carbon completely because this project still produced substantial amount of carbon. However, the benefits of constructing this dam are also substantial, contributing to sustainable infrastructure. When related to the SDGs, these benefits include SDG 2 (Zero Hunger): The dam enhances the planting intensity from 186% to 300%, supplies raw water at a rate of 312 liters per second, equivalent to potable water connections for 28,000 houses, thus driving rapid economic growth and increasing agricultural productivity. SDG 6 (Clean Water and Sanitation): Dams store water and are critical for providing clean water and sanitation facilities. They can also aid in waste management and help improve water quality. SDG 7 (Affordable and Clean Energy): Many dams are utilized to generate hydroelectric power, a form of renewable energy. SDG 8 (Decent Work and Economic Growth): The dam's construction creates new job opportunities, not only in agriculture but also in fish farming and the tourism sector. SDG 15 (Life on Land): The construction of a dam often involves land use changes and can significantly impact local ecosystems and biodiversity. Mitigation measures, such as creating new habitats or corridors for wildlife, can help reduce these impacts. Semantok Dam created a more sustainable infrastructure towards healthier environment, improved human well-being, and boosted economic growth.

10. CONCLUSION

The Semantok Dam Project, identified as one of the National Strategic Projects in Indonesia, is located in the Semantok River Stream in Nganjuk District. It's situated 115 km west of Surabaya City, East Java. With the dam's total length extending to 3.1 km and a height of 31.56 m, it's proudly recognized as “The Longest Dam in Southeast Asia.”

Digital construction technologies such as engineering analysis, digital survey tools, and BIM played a significant role in the project, primarily in acceleration of analysis on design modifications. This acceleration of the decision-making process has resulted in enhanced cost and time efficiency. However, despite BIM's effectiveness as a novel method, it has limitations, notably in computing the impact of carbon emissions on a construction project. This aspect is yet to be fully optimized and requires further development. As a result, a comprehensive analytical calculation is necessary to precisely determine carbon emissions.

In the initial design, rockfills served as the primary material for the dam. However, the quantity available in the existing quarry was insufficient. Consequently, there are two alternatives that emerged to address this problem. Case A proposed sourcing from a new quarry where adequate rockfills were available, but this option posed significant additional costs and potential health concerns for the local community. Case B suggested using the available materials, particularly random soil. However, this would require converting a pine forest area into a quarry, leading to significant land-use change.

Data were collected for both scenarios, including the quantity of materials required according to the initial and revised designs, the dam project's completion schedule, and the distance between the quarry and the project site. This information facilitated the establishment of productivity targets. The productivity targets would, in turn, guide the determination of resource requirements.

The total emissions generated from Case A and Case B were 57,298 tons and 23,914 tons, respectively, resulting in a difference in emissions between the two cases of 33,383.69 tons. The analysis revealed that Case B, which involved transforming a pine forest into a quarry, resulted in lower carbon emissions compared to Case A. However, this land-use change led to a loss of carbon reserves. The project contractor, Hutama Karya, addressed this issue through a carbon recovery plan involving reforestation. More than 6,000 trees were planted around the dam area and at the quarry sites, with an additional 2,000 trees planted on the former quarry land. Vetiver grass was also planted to strengthen the dam’s slopes.

These ongoing recovery efforts demonstrate alignment with SDG 15 - 'Life on Land,' illustrating a commitment to sustainable practices. The dam's construction supports not only SDG 15 but also aligns with other SDGs. These include SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 8 (Decent Work and Economic Growth). The project has thus far demonstrated substantial benefits, including increased planting intensity, a steady supply of raw water, creation of new job opportunities, and the provision of clean, affordable energy.

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