Journal of Sustainable Civil Engineering Insights

Case Study

Environmental Impact of Road Maintenance Projects in Aceh: A Case Study

Siti Mira Maulida[a], Mulyadi Abdullah[b*], Ali Mohammed Aden[c]

[a] *Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia*
[b] *Aceh Public Works and Spatial Planning Office, Banda Aceh, Indonesia*
[c] *Department of Civil Engineering, Gollis University, Rd Number 1, Hargeisa, Somaliland*

[*]Corresponding author: mulyadiabdullah503@gmail.com

Highlights:

- Asphalt production consumes 72% of total energy in road construction.
- CO_2 emissions are highest during the production stage.
- Road construction impacts significant energy use and carbon footprint.
- Strategies suggested to reduce energy use and emissions in construction projects.

Abstract: Constructing and using infrastructure facilities and buildings involves energy consumption, contributing to carbon footprint/greenhouse gas emissions. Road construction is a task that requires a mixture of asphalt at high temperatures, leading to energy consumption and CO_2 emissions. Hence, a study is necessary to estimate the energy consumption and CO_2 emission during pavement construction. The main objective of this study is to determine the energy usage and CO_2 emissions generated during pavement construction. The case study was part of the preservation and reconstruction project on the Banda Aceh — Aceh Jaya border road. The data for this study were collected through interviews and direct observations. The data analysis method used the energy use and GHG emission table for pavement construction and fuel conversion. The findings from this study indicated that during the foundation layer work stage, the total energy consumption was 8.96 × 105 MJ, resulting in 59.74 tons of CO_2 emissions equivalent. In the surface layer work stage, the total energy consumption was 5.13 × 106 MJ, with CO_2 emissions of 386,674 tons. Employing the fuel conversion method, the energy consumption and CO_2 emissions were calculated for each stage of work. During the foundation layer work stage, the total energy consumption was 8.11 × 105 MJ, leading to 60.21 tons of CO_2 emissions. In the surface layer work stage, the energy consumption was 4.70 × 106 MJ, resulting in CO_2 emissions of 348.93 tons. However, among all stages of work on the reviewed project, the production stage of asphalt mixture was identified as the most energy-consuming and CO_2-producing stage, accounting for approximately 72% of the total energy consumption and CO_2 emissions.

Keywords: Energy consumption; CO_2 emissions; road construction; carbon footprint; fuel conversion method

1. Introduction

The construction industry plays a crucial role in national economic growth, significantly contributing to employment, GDP, and the development of physical infrastructure, which drives social and economic progress [1, 2]. However, this sector is also a major source of greenhouse gas (GHG) emissions, accounting for 28% to 39% of global emissions throughout the lifecycle of buildings, from material production to end-of-life processes [3-6]. The construction phase, in particular, has the highest carbon emissions per unit time, exacerbating environmental pollution [7]. Key contributors to these emissions include the production of concrete and steel, energy consumption, and waste production on construction sites [8]. Thus, adopting energy-efficient practices, using alternative materials, and implementing innovative construction methods without compromising structural integrity are essential to mitigate these impacts. Developing carbon emission monitoring models and establishing internationally recognized rating systems for low-carbon construction are crucial for effective GHG management. By focusing on these strategies, the construction industry can promote a sustainable and just future, balancing economic growth with environmental responsibility. This comprehensive approach addresses the immediate need for GHG reduction and supports long-term economic and social benefits, highlighting the interconnectedness of sustainable construction and overall national well-being.

Despite the comprehensive coverage of Indonesia's GHG inventory for industrial, forestry, and transport sectors, emissions from the construction processes of road pavements, particularly flexible pavements, need to be noticed. This omission is significant given the frequent use of flexible pavements in urban and rural roads to accommodate various traffic loads. The construction industry,

Received: 26 May 2024
Revised: 31 May 2024
Accepted: 31 May 2024
Published: 11 June 2024

the fourth-largest contributor to Indonesia's GDP, accounts for a substantial portion of the country's CO_2 emissions, with building sector emissions expected to grow at a 4.5% annual rate as urbanization increases [9]. Between 2009 and 2019, freeway construction produced approximately 29.94 million tons of GHG emissions, underscoring the environmental impact of infrastructure projects [10]. Despite the government's commitment to independently reducing GHG emissions by 29% by 2030 and up to 41% with international assistance, the focus remains on energy and transport sectors that must address construction emissions adequately [11]. Sustainable construction practices, such as using sustainable concrete, still need to be optimally implemented, which could mitigate some of these emissions [12]. Therefore, a holistic approach that includes the construction sector in the GHG inventory and promotes sustainable construction practices is essential for Indonesia to meet its emission reduction targets and achieve environmental sustainability.

This study's primary objective is quantifying flexible pavement construction's energy consumption and carbon footprint. Specifically, it aims to determine the energy usage and CO_2 emissions during the preservation and reconstruction of the Banda Aceh-Aceh Jaya border road, focusing on the foundation and asphalt work stages. The research utilizes the energy consumption and GHG emissions table method for pavement construction and fuel conversion to analyze energy consumption and CO_2 emissions. The focus is predominantly on CO_2 emissions, as most of the carbon in oil is converted into fuel oil. This study was conducted in Leupung, Aceh Besar, during the preservation work on the Banda Aceh - Aceh Jaya border road reconstruction project. Primary data were collected through field observations and interviews with project workers, including information on machine fuel requirements, quantity of machines, project site distance to the AMP, material retrieval distance, and machine types.

By providing a detailed analysis of energy consumption and carbon emissions in the flexible pavement construction process, this paper aims to fill a critical gap in the existing literature. The findings are expected to inform the development of more effective strategies for reducing the environmental impact of road construction projects, thereby supporting Indonesia's broader GHG reduction goals and promoting sustainable development practices in the construction industry.

2. Methods and Data Sources

2.1. Research Procedures and Design

The research design for analyzing energy consumption and carbon footprint in flexible pavement works involved several steps. The initial phase began with identifying the research site, the Banda Aceh-Aceh Jaya border road, specifically focusing on the preservation and reconstruction work in Leupung, Aceh Besar. Subsequently, field observations were conducted to assess the current conditions and identify critical aspects of the construction process. Primary data collection involved interviews with project workers and engineers from PT. Aceh Lintas Sumatra. These interviews gathered detailed information on machine fuel requirements, the number of machines used, the distance from the project site to the Asphalt Mixing Plant (AMP), and the material retrieval distance. Direct observations on-site further supplemented this data, focusing on the types and quantities of equipment used, work stages, and the overall conditions of the construction site. Secondary data was also obtained from specific organizations involved in the project, including technical specifications of the road, fuel consumption rates, and material quantities.

The data processing phase used equations derived from the literature review to estimate energy consumption and carbon footprint. This included calculating the energy use and GHG emissions using the energy use and GHG emission table for pavement construction. This method involved determining material mixture requirements by multiplying the material's specific gravity by the pavement volume. The fuel conversion method was also applied to calculate energy consumption and CO_2 emissions, utilizing specific energy and GHG emissions coefficients based on fuel consumption data.

During the analysis phase, energy consumption and carbon footprint were estimated for each stage of the construction process, focusing mainly on the foundation and surface layer work stages. The study focuses on CO_2 emissions due to the high conversion rate of carbon in oil to fuel oil. A comparative analysis was conducted to validate the findings by comparing results from the energy use and GHG emission table method with those from the fuel conversion method, highlighting any discrepancies.

The final analysis consolidated all data to understand the energy consumption and carbon footprint in flexible pavement construction. Based on the findings, recommendations were made for improving energy efficiency and reducing the carbon footprint in future road construction projects.

2.2. Data Collection

Primary data for this study was directly collected through fieldwork. The primary data included interviews and field observations. Interview data included various aspects such as the distance from the project location to the Asphalt Mixing Plant (AMP), the material retrieval distance to the project site, the fuel requirements for machinery, and the types of machines used. Field observation data included detailed drawings depicting work stages and the quantity and types of tools utilized.

Technical data for the road preservation project on the Banda Aceh – Aceh Jaya border road was gathered through interviews and direct observations. This data included information such as road length, width, and pavement thickness, which is essential for determining the required material mixtures. Detailed technical data can be found in Table 1.

Table 1. Pavement Technical Data

Layer	Thickness (m)	Width (m)	Length (m)	volume (m^3)
Asphalt concrete wearing course	0.04	11	4,200	1,848
AC – Base course	0.06	11	4,200	2,772
Upper based foundation	0.15	11	4,200	6,930
Lower base foundation	0.20	11	4,200	9,240

The materials used in the conservation work project for rebuilding the Banda Aceh – Aceh Jaya border road consist of asphalt and aggregate. The lower foundation layer employs a Class B aggregate with a 0.20 m thickness. Meanwhile, the upper foundation layer uses a Class A aggregate with a thickness of 0.15 m on the pavement layer. Two types of asphalt concrete are involved: Asphalt Concrete – Wearing Course (AC – WC) for the surface layer with a 0.04 m pavement thickness and Asphalt Concrete – Base Course (AC – BC) as the second layer beneath AC-WC with a pavement thickness of 0.06 m.

The laboratory team conducted direct testing to obtain the specific gravity data of the asphalt mixture for the Banda Aceh – Aceh Jaya border road reconstruction. According to the laboratory team's test results, the specific gravity of the asphalt mixture for AC – WC differs from that of AC – BC. For details on the specific gravity data of the asphalt mixtures, refer to Table 2.

Table 2. Aggregate and Asphalt Mixture Specific Gravity

Layer	Specific gravity (t/m^3)
AC - WC	2.64
AC - BC	2.65
Upper base foundation	2.70
Lower base foundation	2.72

Distance data was obtained through interviews and measurements. Two specific distance measurements were collected: the distance from the Asphalt Mixing Plant (AMP) site to the project site for asphalt collection and the distance from the quarry site to the project site for aggregate retrieval. This data is use for calculating transportation-related fuel consumption and associated emissions. Detailed distances from the AMP and quarry to the project site are presented in Table 3.

Table 3. Facilities Distances from the Project Site

Facilities	Site location	Distance (km)
AMP	Teunom	150
Quarry	Lhoknga	16

Fuel consumption information was collected directly in the field through interviews with project staff. Diesel is used as the fuel for all machinery, with consumption rates varying depending on the type of machine. Detailed figures for fuel consumption by different types of machinery are outlined in Table 4.

Table 4. Fuel Consumption Information

Work Item	Equipment	Brand	Production Capacity	Fuel Type	Fuel Consumption
Base layer	Dump Truck	Mitsubishi	30 ton	Diesel	0.25 l/km
	Motor Grader	Mitsubishi	-		0.28 l/t
	Vibrator Roller	Sakai	-		0.10 l/t
Surface layer	Asphalt Mixing Plant	Golden Star	60 ton	Diesel	9.00 l/t
	Dump Truck	Mitsubishi	20 ton		0.16 l/km
	Asphalt Finisher	Sumitomo	20 ton/hr		0.28 l/t
	Tire Roller	Sakai TS 600	-		0.10 l/t
	Tandem Roller	Sakai	-		0.10 l/t

2.3. Data Analysis Method

Calculating estimated energy consumption and greenhouse gas emissions is conducted using the energy use and GHG emission table method for pavement construction and fuel conversion. The method table for energy use and GHG emission in pavement construction provides calculations based on the equation (1). Data on material mixture requirements is derived from multiplying the material's specific gravity by the pavement volume, as calculated by equations. (2) and (3). This data is crucial for establishing fuel consumption levels and assessing energy consumption and greenhouse gas emissions. Calculations involve utilizing equations (4) in the fuel conversion method and equation (5) for energy consumption.

$$E = W_{ca}\ X\ \alpha_e \qquad (1)$$

$$Wa = p\ x\ l\ x\ t\ x\ Bj \qquad (2)$$

$$Wca = p\ x\ l\ x\ t\ x\ Bj \qquad (3)$$

$$E = Kb\ x\ Cv \qquad (4)$$

$$GHG \quad = Kb\ x\ Fe \qquad (5)$$

where: E represents energy consumption (MJ); Wa stands for weight of aggregate mix (tons); W_{ca} indicates weight of asphalt mix (tons); α_e is the coefficient number obtained from the energy table (MJ/ton); p represents road length (m); l stands for road width (m); t indicates the thickness of the asphalt road layer (m); and Bj represents the specific gravity of the asphalt mixture; Kb represents fuel consumption in liters, Cv stands for calorific value in MJ per liter, GHG indicates greenhouse gas emissions in kg of CO_2, and Fe denotes emission factor in kilograms of CO_2 per liter as shown in Table 5.

Table 5. Conversion Factor for Energy and Emission

Fuel Type	Density (kg/l)	Calorific Value (MJ/l)	Emission Factor ($kgCO_2$/l)
Crude Oil	0.84	35.83	2.63
Diesel Fuel	0.83	35.99	2.67

3. Results

3.1. Construction Material Quantification

The conservation project for reconstructing the Banda Aceh — Aceh Jaya border road involves using asphalt and aggregate materials. The total aggregate mix required for the 4,200 m road reconstruction is specified for the workers. Similarly, the total amount of asphalt needed for the project matches the aggregate mix requirement. Details of the aggregate and asphalt mix requirements are provided in Table 6.

Table 6. Materials needed in construction

Layers	Volume (m^3)	Specific Gravity (t/m^3)	Weight (t)
Upper base layer	6,930	2.70	18,738.72
Lower base layer	9,240	2.73	25,188.24
Surface wearing course	1,848	2.64	4,882.42
Surface base course	2,772	2.65	7,354.12
	Weight total		56,163.50

3.2. Fuel Consumption

Calculation of fuel consumption is the outcome derived from the fuel requirements of heavy equipment usage. Fuel consumption calculation will be segmented by the type of work involved, such as the foundation and surface layer work. Regarding the foundation layer, fuel consumption calculation will be based on its various stages, including transportation and construction. The summary of the fuel consumption calculation results is presented in Table 7.

Table 7. Fuel Consumption List

Work Items	Activities	Equipment	Brand	Fuel Type	Fuel consumption (l)
Base layer	Transportation	Dump Truck	Mitsubishi	Diesel	5,860.00
	Construction	Motor Grader	Mitsubishi		16,692.25
		Vibrator Roller	Sakai		
Surface layer	Production	Asphalt Mixing Plant (AMP)	Golden Star	Diesel	110,128.79
	Transportation	Dump Truck	Mitsubishi		14,683.84
	Construction	Asphalt Finisher	Sumitomo		5,873.54
		Tire Roller	Sakai TS 600		
		Tandem Roller	Sakai		

3.3. Data Analysis

3.3.1. Calculation using the Energy Use and GHG Emission Table for Pavement Construction

As depicted in Table 8, the results show that 632,548.22 MJ of energy is consumed during the transport phase, leading to greenhouse gas emissions of 42,169.88 kg. In the construction phase, energy consumption totals 263,561.76 MJ, resulting in greenhouse gas emissions of 17,570.78 kg. The calculation reveals that the energy consumption during the transport stage exceeds that of the construction stage for the foundation layer work. This increase in energy consumption is attributed to the volume of the aggregate mixture, the high energy demand during transportation, and the considerable distance between the quarry and the project site. Consequently, the transport stage generates more greenhouse gases than the construction stage, as higher energy usage increases emissions.

For the surface layer, the production stage consumes 3,365,046.30 MJ of energy, resulting in 269,203.70 kg of greenhouse gases. During the transport phase, 1,651,931.82 MJ of energy is consumed, producing 110,128.79 kg of greenhouse gases. In the construction phase, energy consumption is 110,128.79 MJ, leading to 7,341.92 kg of greenhouse gases. The energy consumption during the production stage of the asphalt mixture surpasses that of the transport and construction stages. This is primarily due to the high temperatures required for asphalt mixing, which range from 160 °C to 200 °C. High temperatures necessitate more fuel, resulting in increased fuel consumption. Additionally, the quantity of asphalt mixture and the prolonged use of equipment contribute to the higher energy consumption observed during the production stage.

Based on the calculations, the production stage also emits more greenhouse gases than the transport stage. This is directly linked to the energy consumption at each stage, where higher energy usage increases greenhouse gas emissions. Factors such as fuel consumption, heavy machinery usage, and the distance for asphalt transportation to the project site contribute to this rise.

Table 8. Calculation of Energy Consumption and Greenhouse Gas (GHG) Emissions based on GHG Emission Table

Work items	Activities	Weight (t)	α_e (MJ/t)	α_g (Kg/t)	Energy Use (MJ)	GHG (Kg)
Base Layer	Transportation	43,926.96	144	0.96	632,548.22	42,169.88
	Construction		6	0.40	263,561.76	17,570.78
Surface Layer	Production	12,236.54	275	22.00	3,365,046.3	269,203.70
	Transportation		135	9.00	1,651,931.82	110,128.79
	Construction		9	0.60	110,128.79	7,341.92

3.3.2. Calculation by Fuel Conversion Method

The results in Table 9 show that 210,901.40 MJ of energy is consumed during the transport stage, emitting 15,646.20 kg of greenhouse gases. In the construction phase, energy consumption amounts to 600,754.08 MJ, producing 44,458.29 kg of greenhouse gases. The calculation reveals that the construction stage consumes more energy than the transport stage in the foundation layer work. This disparity is due to multiple types of machinery over a road length of 4,200 meters during the construction phase, leading to increased fuel consumption. Conversely, during the transportation stage, the quarry retrieval distance is shorter, precisely 16 km from the project site, and only one type of machine is used, resulting in a slight reduction in fuel consumption. Consequently, the construction phase generates more greenhouse gases than the transport phase. Factors such as fuel consumption, the use of heavy machinery, and the distance materials need to be transported to the project site contribute to this increase.

As for the surface layer works, a similar trend could be seen where the production stage consumes 3,963,535.08 MJ of energy, producing 294,043.86 kg of greenhouse gases. During the transport phase, 528,471.34 MJ of energy is consumed, producing 39,205.85 kg of greenhouse gases. In the construction phase, energy consumption is 211,388.56 MJ, producing 15,682.34 kg of greenhouse gases. The energy consumption during the production stage of the asphalt mixture surpasses that of the transport and construction stages. This is primarily due to the high fuel utilization required for asphalt mixture production, which amounts to 9 liters per hour. Energy usage during transportation is also significant due to the distance of 150 km between the AMP site and the project site. Conversely, the construction stage requires minimal fuel, resulting in relatively lower energy consumption than the production and transport stages. Consequently, the production stage emits more greenhouse gases than the transport stage. This is directly linked to the energy consumption at each stage, where higher energy consumption results in increased greenhouse gas emissions.

Table 9. Calculation of Energy Consumption and Greenhouse Gas (GHG) Emissions based on Fuel Consumption Method

Work items	Activities	Kb (l)	Cv (MJ/l)	Fe (Kg/l)	Energy Use (MJ)	GHG (Kg)
Base Layer	Transportation	5,860.00	35.99	2.67	210,901.40	15,646.20
	Construction	16,692.25			600,754.08	44,458.29
Surface Layer	Production	110,128.79			3,963,535.08	294,043.86
	Transportation	14,683.84			528,471.34	39,205.85
	Construction	5,873.54			211,388.56	15,682.34

3.3.3. Comparison of Estimated Calculation of Energy Consumption and Greenhouse Gas Emissions

Figure 1 illustrates that the total energy consumed in flexible pavement work is higher with the energy use and GHG emission for the pavement construction method than the fuel conversion method. This is attributed to the high efficiency in energy consumption during the production stage and the extended use of equipment. Analyzing the different stages of work, it is evident that in the surface layer work, the production stage accounts for the highest energy consumption, specifically 3,963,535.08 MJ, when utilizing the fuel conversion method, surpassing the energy consumption in other stages. The significant rise in energy usage results from using tools beyond their service life, excessive fuel consumption, and longer distances for tool retrieval that necessitate extra fuel.

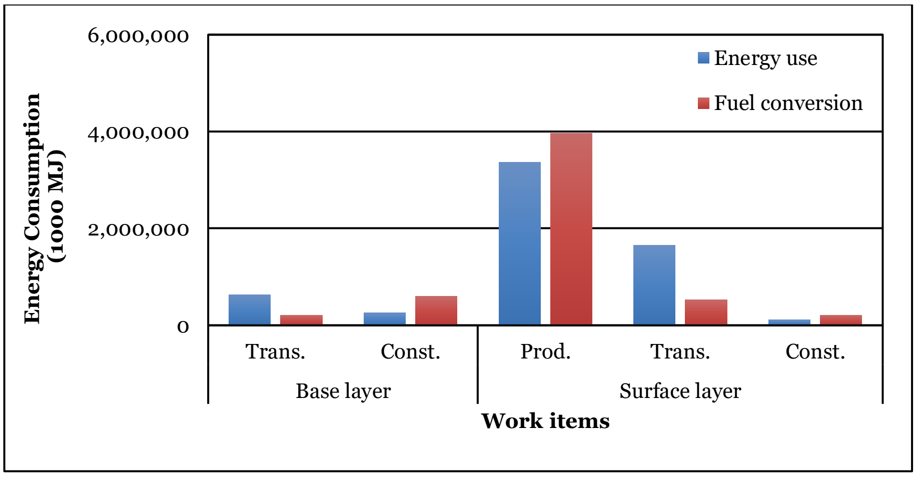

Figure 1. Energy Consumption Estimation Comparison

Calculating CO_2 emissions (Figure 2) during pavement construction yields higher results when using the energy use and GHG emissions table method than the fuel conversion method. This difference is attributed to the energy consumption levels; higher energy consumption leads to increased greenhouse gas emissions. Specifically, the production stage of the asphalt mixture stands out by generating a substantial amount of 294,043.86 kg of greenhouse gas using the fuel conversion method, surpassing emissions from other stages. The rise in greenhouse gas emissions is closely linked to energy consumption levels. It is further exacerbated by using tools that have exceeded their operational lifespan and transporting materials over long distances, necessitating additional fuel.

Drawing from the comparison above, heightened energy consumption levels can directly contribute to elevated greenhouse gas emissions. Mitigating this surge in energy consumption involves strategies such as reducing fuel usage, opting for machinery that is in optimal condition or within its expected lifespan, and carefully considering the transportation distance of materials and the distance to the project site.

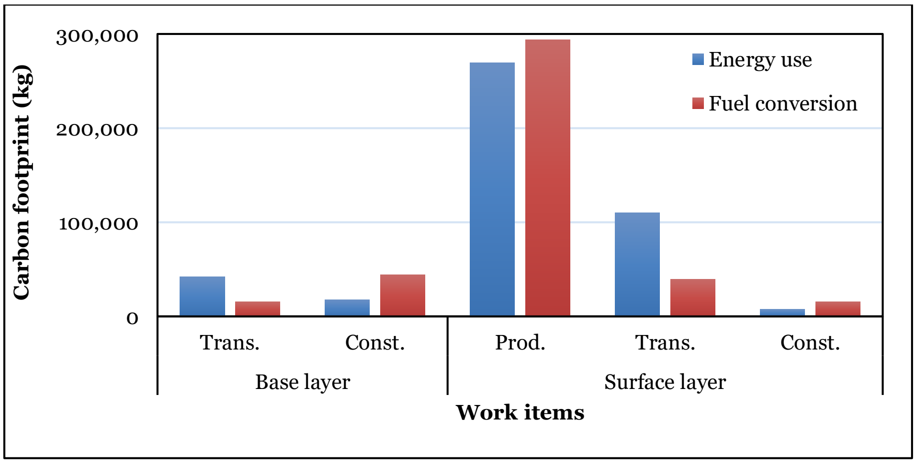

Figure 2. GHG Emission Estimation Comparison

3.4. Discussion

Based on the analysis, it is evident that the estimated energy consumption and CO_2 emissions for pavement construction using the energy use and GHG emission table method exceed those from the fuel conversion method. The findings from the Banda Aceh – Aceh Jaya border road reconstruction project highlight that asphalt mixture production activities are the most energy-intensive and CO_2-emitting tasks. Among the various stages examined, the production phase, as analyzed using the energy use and GHG emission table method, emerges as the most energy-intensive, contributing to approximately 72% of the project's total energy consumption and emissions.

The study identifies the asphalt mixture production stage as critical for improving energy efficiency and refining processes. Enhancing efficiency can be achieved by selecting an AMP location closer to the project site and considering the age and condition of the AMP equipment. These measures aim to directly reduce greenhouse gas consumption and emissions while indirectly boosting greenhouse gas absorption through greening initiatives in the surrounding area. Greening represents one of the most straightforward strategies to reduce greenhouse gas emissions. The foundation layer work consumes minimal energy and produces fewer greenhouse gas emissions due to the proximity of the quarry to the project site, only 16 km away, which reduces fuel usage. However, monitoring machinery conditions during this stage is essential, as suboptimal combustion conditions can increase energy consumption and greenhouse gas emissions.

The substantial distance between the project's AMPs during the surface layer work results in significant fuel consumption. Transporting materials from distant locations increases energy consumption and greenhouse gas emissions. Therefore, locating the nearest AMP to the project site and ensuring optimal combustion conditions for heavy equipment to mitigate the increased energy consumption and emissions is crucial. The fuel conversion method is recommended to accurately determine CO_2 emissions in flexible road pavement construction, as it provides a more precise assessment by directly evaluating the fuel requirements based on the engine and tool conditions.

4. Conclusion

Based on the analysis and discussion conducted in the previous chapter, the following conclusions are drawn:

The total energy consumption for the conservation work of reconstructing the Banda Aceh – Aceh Jaya border road is 6,023,216.89 MJ using the energy use and GHG emission table method for pavement construction, while the fuel conversion method results in 5,515,050.28 MJ. A significant increase in energy consumption directly correlates with higher greenhouse gas emissions. The total CO_2 emissions from the conservation work using the energy use and GHG emissions table method are 446,415.08 kg, whereas the fuel conversion method yields 409,146.55 kg. The scale of these greenhouse gas emissions has a considerable environmental impact. Notably, surface layer work is identified as the most energy-consuming and CO_2-emission-producing task. The energy consumption and CO_2 emissions estimation through the energy use and GHG emission table method surpasses that of the fuel conversion method, primarily due to the quantity of material mixture and the high energy consumption efficiency value. Fuel consumption and material retrieval distance are crucial factors in determining the overall energy consumption and carbon footprint.

The current study only covers the review of foundation layer work and asphalt work. However, it does not delve into the stages of producing aggregate mixtures. Therefore, future studies should include additional stages such as aggregate mixture production, preparation stages, and land clearance. For future assessments, it is advisable to opt for the fuel consumption conversion method, as it provides immediate information on the required materials based on machine conditions and tools utilized, ensuring results align closely with actual conditions. To mitigate excessive energy consumption and reduce the carbon footprint, measures such as minimizing fuel usage, selecting new machines or ensuring existing ones are within their operational lifespan, and monitoring the distance for material retrieval and AMP proximity to the project site are essential. Indirectly reducing energy consumption and the consequent carbon footprint can also be achieved through greening initiatives, a simple yet effective method to curb greenhouse gas emissions. Extensive greening efforts enhance greenhouse gas absorption, reducing emissions released into the atmosphere.

Author Contributions:

Conceptualization, M. Abdullah and S.M. Maulida; methodology, M. Abdullah; software, S.M. Maulida; validation, M. Abdullah., S.M. Maulida and A.M. Aden; formal analysis, M. Abdullah; investigation, S.M. Maulida; resources, M. Abdullah; data curation, S.M. Maulida; writing—original draft preparation, S.M. Maulida; writing—review and editing, A.M. Aden; visualization, A.M. Aden; supervision, M. Abdullah; project administration, M. Abdullah; funding acquisition, M. Abdullah. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Furtado, Felipe Casa Nova, Fátima de Cássia de Athayde Borille, Andréa de Melo Santos, Eliana Cristina Barreto Monteiro, and Galba Maria de Campos-Takaki. "Contribution of civil construction in the emission of gases involved with greenhouse effect." Seven Editora (2023). doi: https://doi.org/10.56238/alookdevelopv1-072
2. Kanafani, Kai, Jonathan Magnes, Søren Munch Lindhard, and Maria Balouktsi. "Carbon emissions during the building construction phase: A comprehensive case study of construction sites in Denmark." Sustainability 15, no. 14 (2023). doi: https://doi.org/10.3390/su151410992
3. Saka, Najim. "An assessment of the impact of the construction sector on the gross domestic product (gdp) of nigeria." Journal of Surveying, Construction and Property 13, no. 1 (2022). doi: https://doi.org/10.22452/jscp.vol13no1
4. Lopes, Jorge. "Construction in the economy and in national development." In Research Companion to Construction Economics, pp. 104-125. Edward Elgar Publishing (2022). doi: https://doi.org/10.4337/9781839108235
5. Li, Long, and Yinting Li. "The spatial relationship between CO2 emissions and economic growth in the construction industry: based on the Tapio decoupling model and STIRPAT model." Sustainability 15, no. 1 (2022). doi: https://doi.org/10.3390/su15010528
6. Crawford, Robert H. "Greenhouse gas emissions of global construction industries." In IOP Conference Series: Materials Science and Engineering, vol. 1218, no. 1, p. 012047. IOP Publishing, (2022). doi: https://doi.org/10.1088/1757-899x/1218/1/012047
7. Labaran, Yahaya Hassan, Vivek Shankar Mathur, Shehu Usman Muhammad, and Auwal Alhassan Musa. "Carbon footprint management: A review of construction industry." Cleaner Engineering and Technology 9 (2022). doi: https://doi.org/10.1016/j.clet.2022.100531
8. Kaja, Nagaraju, and Stuti Goyal. "Impact of Construction Activities on Environment." Resource 45 (2023). doi: https://doi.org/10.29121/ijetmr.v10.i1.2023.1277
9. Amelinda, Adanya T., and Subiakto Soekarno. "Financial feasibility study of carbon capture, utilization, and storage project in west java, Indonesia." European Journal of Business and Management Research 8, no. 3 (2023). doi: https://doi.org/10.24018/ejbmr.2023.8.3.1969
10. Putriyana, Lia, Yunus Daud, Muhammad Aziz, and Nurry Widya Hesty. "Evaluation and ranking of the CO_2 storage potential in low to medium temperature geothermal fields in Indonesia." Case Studies in Chemical and Environmental Engineering 8 (2023). doi: https://doi.org/10.1016/j.cscee.2023.100406
11. Husada, Vikram Surya, Nur Allif Fathurrahman, Cahyo Setyo Wibowo, and Iwan Erar Joesoef. "Juridical review on the mandatory biodiesel program for maintaining national energy security in Indonesia." In IOP Conference Series: Earth and Environmental Science, vol. 1187, no. 1, p. 012036. IOP Publishing, (2023). doi: https://doi.org/10.1088/1755-1315/1187/1/012036
12. Raihan, Asif, Monirul Islam Pavel, Dewan Ahmed Muhtasim, Sadia Farhana, Omar Faruk, and Arindrajit Paul. "The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia." Innovation and Green Development 2, no. 1 (2023). doi: https://doi.org/10.1016/j.igd.2023.100035