International Journal on Advanced Science Engineering Information Technology

Vol.9 (2019) No. 5
ISSN: 2088-5334

Estimating and Reducing the Release of Greenhouse Gases in Local Road Pavement Constructions

Fajar Sri Handayani[#], Florentina Pungky Pramesti[*1], Mochamad Agung Wibowo[+], Ary Setyawan[*2]

[#]Doctoral Program in Civil Engineering, Engineering Faculty, Sebelas Maret University, Surakarta, Indonesia
E-mail: [#] fajarhani@ft.uns.ac.id

[*]Civil Engineering Department, Engineering Faculty, Sebelas Maret University, Surakarta, Indonesia
E-mail: [1]f.p.pramesti@ft.uns.ac.id; [2]cenase@yahoo.com

[+]Civil Engineering Department, Engineering Faculty, Diponegoro University, Semarang, Indonesia
agungwibowo360@gmail.com

***Abstract*— Local roads, which comprise 91% of the road networks in Indonesia, are a vital part of the transportation infrastructure. The construction of local roads has had some negative impacts on the environment, one of the most significant of which is the release of greenhouse gases (GHG). In order to develop a strategy for sustainable development in transportation infrastructure, it is essential that GHG emissions be reduced in the local road construction cycle. The aims of this study were to estimate the release of GHG and to elaborate on efforts to reduce GHG emissions in the construction of both rigid and flexible local road pavements. First, a life cycle assessment was performed to calculate the energy consumption and amount of GHG emissions. Next, some possible approaches were explored and elaborated on to seek opportunities to reduce GHG emissions, and therefore, enhance the sustainability of local road constructions. The results showed that material processing and material transportation contributed to 74.0-75.2% and 24.7-26.5% of GHG emissions, respectively. It is also known from the stepwise analysis that the significant predictor to form the amount of GHG both on the rigid and flexible pavement is the distance of the aggregate source to batching/asphalt mixing plant. Hence, the strategies for the reduction of GHG emissions, in this case, might be carried out by substituting current construction materials (cement and asphalt) with less intensive GHG emissions materials, and by reducing the distance for the transportation of the aggregates. The result shows that the first proposed strategy, which is substituting cement or asphalt with fly ash and reclaimed asphalt reduces more GHG than the second one.**

***Keywords*— greenhouse gases emissions; local roads; rigid pavements; flexible pavements.**

I. INTRODUCTION

Civil infrastructure, especially roads, is vital and essential to the productivity of a society and the economic development of a nation. Local road networks support the productive mobility of goods and people by connecting suburban areas. Based on the data from the Ministry of Public Works and Housing, there was 423,578 km of local roads in Indonesia in 2015, with 59% of them being in good condition. There is an increasing demand for new and stable local roads to ensure the growth of the local economy. However, the appropriate strategy for meeting this demand is to provide a local road network management that takes into account the aspect of sustainability [1].

Local roads in Indonesia are commonly constructed with flexible pavements, while recent developments show that there has been an increase in the construction of new local roads with rigid pavements. The reasons for the latter choice are their longer service life and relatively easy maintenance. However, both types of pavements are being widely used and have exhibited advantages and disadvantages.

Further, the construction of rigid pavements impacts the environment significantly in the form of greenhouse gas emissions. This needs to be seriously considered because the majority of the contractors who are working on local roads are local contractors who might be less concerned about the impact of the release of greenhouse gases into the atmosphere during the construction of roads. A preliminary step towards anticipating the adverse environmental impacts of local road constructions is to assess the number of greenhouse gases being released while the construction is going on. By making a quantitative estimate of greenhouse gas (GHG) emissions from road construction projects, a complete assessment and life cycle measurement can be carried out on the construction processes for rigid and flexible pavements.

A life-cycle assessment (LCA) is used to calculate the amount of energy that is consumed and the number of greenhouse gases that are released into the atmosphere during the life of a product. In other words, an LCA is a method for evaluating the environmental impact of a product during its life cycle. The LCA has four study phases, i.e., the definition of goal and scope, inventory analysis, impact assessment, and interpretation [2].

The following are some of the researches that were performed on the sustainability aspect of road constructions: Park et al. developed a model for estimating the environmental load in terms of social overhead for the road-planning phase through an LCA [3]. Kokkaew and Rudjanakanoknad advanced a green road infrastructure assessment model by combining the economic index and environmental performance of a project [4]. Liu et al, Wang et al, and Ma et al, examined the impact of energy consumption and GHG emissions on the environment by using the LCA approach and emissions databases for highway [5]–[7]. Mulyana examined GHG emissions by referring to the Intergovernmental Panel on Climate Change (IPCC) case study guide on national roads in Indonesia [8]. Li et al, O'Born, Babaee et al, and Li et al, studied the energy consumption and GHG emissions for bridges, railway, and fast track using an approach that referred to the LCA [9]–[12]. Civil engineering construction projects are unique in the generation of various quantities of GHG emissions. These depend on the materials, the construction method, and the execution of the project. Unfortunately, to date, no research has been carried out to assess the amount of GHG emissions released during local road construction projects, using both rigid and flexible pavements. The above studies did not analyze in detail the efforts to reduce emissions. In addition, they focused on cases in developed countries and on highways.

Therefore, this study estimated the release of GHG and investigated the reduction of GHG emissions in local road constructions using both rigid and flexible pavements. An estimation was made of the amount of GHG emissions released using the LCA method with the Ecoinvent and TRACI 2.1 databases [13].

II. MATERIALS AND METHOD

A. Estimation Methods

The energy sector emits GHG consisting of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). GHG emissions are generated by fuel combustion, which is the oxidation of fuel in a device with the aim of providing the mechanical work to a process. The simplest method of calculating emissions is to use the activity data and emission factor, according to the IPCC Guidelines [14]:

$$GHGemissions = activitydata \times emissionfactor \tag{1}$$

The activity data is the number of human activities associated with GHG emissions. The activity data in this study comprised the main activities at the stage of material production and pavement construction. An example of activity data is the volume of fuel oil used or coal consumed for pavement works. The emission factor is a coefficient that shows the number of emissions per unit of activity. Data on the number of emissions released for each pavement activity were based on the Ecoinvent database 3.3. Since the most dominant component of GHG is CO_2, the estimation of the GHG emissions was converted into units of CO_{2e} (carbon dioxide equivalent). The conversion of the CO_2 generated in GHG emissions was conducted using the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI 2.1) database.

B. Local Road Pavement Construction Stages

The construction of road pavements was divided into 4 main stages: the production of raw materials, the concrete-mixing at the batching plant (BP) or the asphalt-mixing process at the asphalt mixing plant (AMP), the transportation to the site, and the construction at the project site. The four main stages and unit processes that released GHG emissions are shown in Table 1.

TABLE I
FOUR MAIN STAGES AND UNIT PROCESSES OF RIGID AND FLEXIBLE PAVEMENTS

Stage	Unit processes on rigid pavement	Unit processes on flexible pavement
The production of raw materials	The production of gravel and sand The production of steel The production of Cement	The production of gravel and sand The production of asphalt The production of filler
The concrete-mixing or the asphalt-mixing process	Transportation of sand to the BP Transportation of gravel to the BP Transportation of cement to BP Mixing process in batching plant	Transportation of aggregate to AMP Transportation of sand to AMP Transportation of asphalt to AMP Transportation of filler to AMP Mixing process in asphalt-mixing plant
The transportation to the site	Transportation to site GHG release due to mixer rotation	Transportation to site
The construction at the site	Steel transportation to the site Work floor Concrete spreading	Sub-base course Base course Asphalt binder spraying Surface course

C. Case Study

This study was designed as exploratory case studies of rigid and flexible pavements with the aim of estimating the GHG emissions of material production activities and pavement constructions. In addition, it was also aimed at identifying the unit processes for rigid and flexible pavement activities and evaluating further their environmental impacts. Case studies 1, 2, 3, 4, 5 and 6 were local road structure improvement projects with rigid pavements, and case studies 7, 8, 9, 10, 11, and 12 were local road structure improvement projects with flexible pavements. The data required for the analysis of the raw materials production stage included the data on the work volume and the Life Cycle Inventory (LCI) of the processing aggregates, namely, iron and cement. Meanwhile, the Life Cycle Inventory data that was used included the secondary data obtained from previous researches on the extraction of raw materials for making rigid pavements. The LCI data used are described in Table 2 [15]–[17].

For the flexible pavements, the types of pavement materials and their required volume in the analysis of the raw materials production stage and the Life Cycle Inventory (LCI) data included the processing of asphalt, asphalt binder, aggregates, and fillers. As for the Life Cycle Inventory, the data used were the secondary data obtained through previous researches. The LCI data used are shown in Table 3 [18].

The data needed for the analysis of the raw materials production stage were the data on the location of the batching plant, the location of the quarry for the raw materials, the vehicles used for the transportation of raw materials, the fuel usage for the batching plant operations, and the release of GHG in the processing at the batch mixing plant. From the results of the research on the Life Cycle Inventory by the National Ready Mixed Concrete Association (NRMCA), Bushi et al. found that the energy consumption during the operation at the batch mixing plant was as shown in Table 4 [19].

The LCI data used with regard to the batch mixing plant, transportation to site, and concrete overlay stages are shown in Table 5 [18]. The LCI database used in transportation to the site and the construction at the flexible pavement project site is shown in Table 6 [18].

TABLE II
GHG EMISSIONS FOR RIGID PAVEMENT RAW MATERIALS PRODUCTION

Material	Amount of GHG ($kgCO_{2e}$ / kg-material)	Source
Cement	1.0670	Merceu et al., 2007
Aggregate	0.0032	Zapata and Gambatese, 2005
Steel	2.0000	Hughes and Hare, 2012

TABLE III
GHG EMISSIONS IN THE PRODUCTION OF FLEXIBLE PAVEMENTS PER TON

Material	GHG emission (kg CO_{2e}/t)
Asphalt	285
Asphalt binder	221
Gravel	10
Sand	2.50
Filler	10

TABLE IV
ENERGY USAGE IN CONCRETE MIXING PROCESS

Energy Type	Usage	Unit	Conversion (unit/m^3)
Electricity	3.8600	kWh	2.9512 kWh
Natural Gas	9.9234	MJ	7.5959 MJ
Fuel Oil	0.0101	kg	0.0077 kg
Diesel	0.3710	Gallon	0.4853 Gal
Gasoline	0.0020	Gallon	0.0026 Gal
LPG	1.2091	MJ	0.9255 MJ

TABLE V
EMISSION SOURCES, GAS AND EMISSIONS GENERATED BY ROAD CONSTRUCTION EQUIPMENT

Sources of emissions	Name of gas produced	The emission release (kg)
Truck 7,5 ton Metric per 1 ton.km	CO_2	0.353
	CH_4	2.29×10^{-6}
Truck 16-32 ton Metric per 1 ton.km	CO_2	0.119
	CH_4	9.89×10^{-7}
Solar per 1 gallon	CO_2	10.16047
LPG per 1 kg	Butane	1.65×10^{-4}
	Propane	1.65×10^{-4}
Electricity production per 1 kWh	CO_2	0.958
	Chloroform	8.10×10^{-9}
	Trichloroethane	1.65×10^{-9}
	CH_4	9.05×10^{-6}
Oil per 1 kg	NMVOC	0.01
Natural gas per 1 MJ	CO_2	0.056
	CH_4	1.70×10^{-5}
Fuel per 1 gallon	CO_2	8.89041
Truck Mixer per 1 ton.km	CO_2	0.119
	CH_4	9.89×10^{-7}
Truck Mixer Dozer per our	CO_2	16
	CH_4	1.19×10^{-4}
Vibrator per our	CO_2	2.92
	CH_4	3.00×10^{-5}
Water Tanker per ton.km	CO_2	0.353
	CH_4	2.29×10^{-6}

TABLE VI
SOURCES OF EMISSIONS, GAS, AND EMISSIONS PRODUCED BY ROAD CONSTRUCTION EQUIPMENT

Sources of Emission	Name of gas produced	The emission release (kg)
Tandem Roller per our	CO_2	24.8
	CH_4	0.000126
Pneumatic Tire Roller per our	CO_2	24.8
	CH_4	0.000126
Asphalt Finisher per our	CO_2	24.8
	CH_4	0.000126
Motor Grader per our	CO_2	24.8
	CH_4	0.000126
Truck Water Tank per our	CO_2	5.06
Air compressor per our	CO_2	3.58
	CH_4	0.0000546
Asphalt distributor per our	CO_2	5.06

III. RESULTS AND DISCUSSION

A. Greenhouse Gas Emissions Estimate

At the pavement material processing stage, the number of emissions from construction materials was estimated by multiplying the quantity of the materials with the GHG value resulting from the production of raw materials. The value was obtained through the approach in previous research related to the material used (Tables 2 or 5).

For the estimation of emissions in the transportation process, i.e. in the process of transporting the material to the mixing site and the phase of transporting the pavement mixture to the site, the outline was done by multiplying the productivity of the means of transportation, in ton kilometre (t.km) units, with the emission value generated by the road construction equipment (Tables 3 or 4). The productivity of the transportation equipment was influenced by the capacity of the bucket, the distance from the quarry to the mixing plant, the distance from the mixing plant to the site, and the number of repetitions of the means of transportation. The estimated amount of GHG emissions in the mixing process was calculated by multiplying the fuel consumption used per unit with per unit of GHG. At the stage of the construction at the project site, the estimated amount of emissions was calculated by multiplying the time in hours that the construction equipment was used with the value of the GHG emissions generated by the equipment (Table 6).

The results of the calculations for the GHG emissions generated by the use of rigid pavement materials in case study 1 are presented in Table 7.

The results of the calculations for the GHG emissions due to the transportation of the materials from the unit processes to the batch mixing plant and for the release GHG at the batch mixing plant for case study 1 are presented in Tables 8 and 9, respectively.

At the stage of the transportation of the concrete to the site, GHG was released during the delivery of the concrete and when the mixer on the truck was rotating during the trip. The amount of GHG emissions that resulted from the transportation of the concrete was calculated based on the distance of the mixer truck from the project site and the emissions generated from the energy used for the rotation of the engine mixer.

TABLE VII
EXAMPLES FOR CALCULATING THE GHG EMISSIONS FROM THE USE OF MATERIALS

Material	**Usage (kg)**	**GHG emission/kg-material (kgCO$_{2e}$)**	**GHG emission (kgCO$_{2e}$)**
Cement	884,501.84	1.067	943,763.46
Aggregate	3,637,304.71	0.003	11,639.38
Steel	219,843.39	2.000	439,686.78

TABLE VIII
EXAMPLES FOR CALCULATING THE GHG EMISSIONS FROM THE TRANSPORTATION OF MATERIALS TO THE BATCH MIXING PLANT

Material	**Distance to BP (km)**	**GHG emission kgCO$_2$e/t.km**	**GHG emission kgCO$_{2e}$**
Sand	90.30	0.35305725	95,643.21
Gravel	31.20	0.35305725	47,256.08
Cement	169.00	0.11902472	36,046.40

TABLE IX
RELEASE OF GHG IN THE BATCH MIXING PLANT

Energy Type	**Usage (kg)**	**GHG per unit (kgCO$_{2e}$)**	**GHG emission (kgCO$_{2e}$)**
Electricity	8,292.564	0.9582	7,946.16
Natural Gases	16,239.807	0.0564	916.33
Oil	16.463	0.0000	0.00
Solar	1,037.557	10.1605	10,542.10
Fuel	5.559	8.8904	49.42
LPG	1,978.691	0.0000	0.00
Sum of Emission			19,454.01

The discharge of GHG at the stage of the concrete spraying work in the field started from the process of transporting the steel to the project. The next stage was the making of lean concrete at the work floor. The amount of GHG emissions from the mixer tanker was calculated by multiplying the total time of fuel consumption in the rolling mixer and the watering of the concrete for 28 days using water tankers, with GHG being released from the water tankers per hour. By using the same calculation concept, the resulting amount of GHG emissions from the flexible pavement was calculated.

The average percentages of GHG emissions are presented in Fig. 1 and 2. The recapitulation percentages of GHG emissions on the rigid and flexible pavements are shown in Fig. 3.

It was known that the most critical stage in the release of greenhouse gases was during the production of raw materials, especially in the unit processes for the production of portland cement and asphalt.

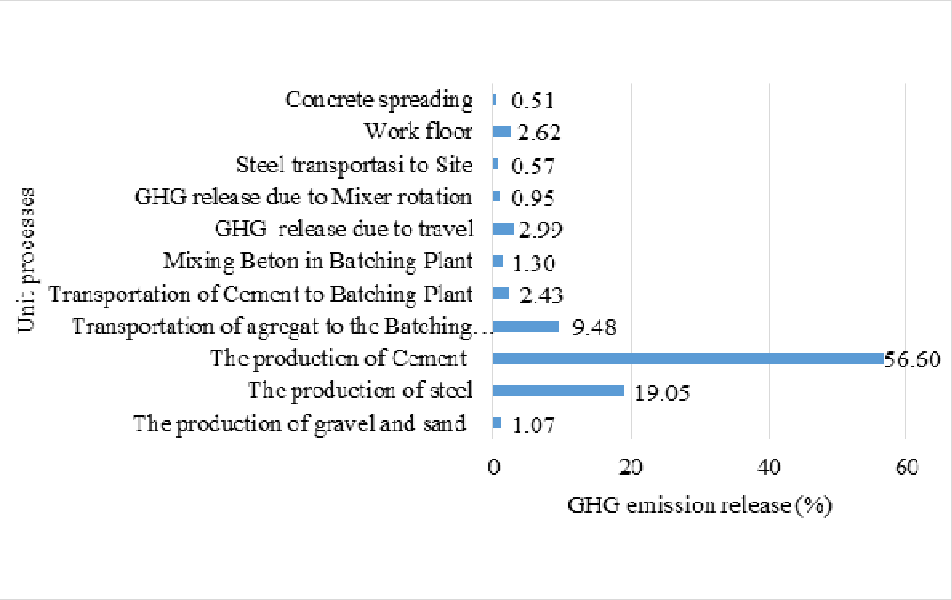

Fig. 1. Percentages of GHG emissions released from rigid pavements

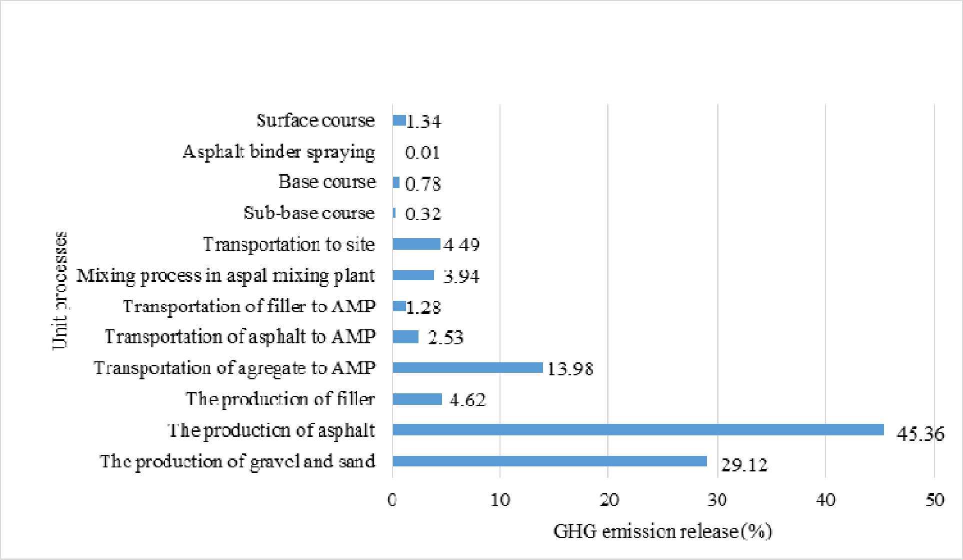

Fig. 2. Percentages of GHG emissions released from flexible pavements

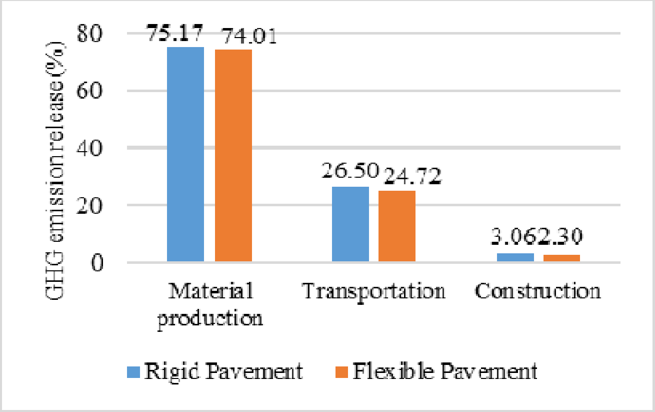

Fig. 3. Recapitulation percentages of GHG emissions released

B. *Potential Reduction in Greenhouse Gas Emissions*

The emissions produced in the calculations above were those that were released during the manufacture of the materials, the transportation of the materials, and the construction of the pavements. Therefore, the emissions produced could be lowered if fewer natural resources were used and transportation activities were reduced. A further analysis was required to determine which material unit process or transportation activity was the dominant factor (significant predictor) of emissions reduction and what percentage of it needed to be reduced. Statistical methods were applied in an effort to determine the variables (predictor variables) that affected the amount of greenhouse gases emissions. A stepwise analysis was used to select the independent variable, xi that was to be used as the dominant input to the regression model to estimate the magnitude of the independent variable, y in each xi unit.

The dependent variable (Y) in this research was the amount of greenhouse gas emissions produced on the rigid (Y_R) and flexible (Y_F) pavement projects. In the case studies of the rigid pavement project, the independent variables were the distance of: the location of the batching plant to the location of the project (X_1); the aggregate source to the batching plant (X_2); the sand source to the batching plant (X_3); the cement source to the batching plant (X_4); the reinforced steel source to the location of the project (X_5); and the volume of: the aggregate (X_6); the cement (X_7); and the concrete (X_8). Meanwhile, the independent variables in the case studies on flexible pavements were the distance of the location of the AMP to the location of the project (X_9); the aggregate source to the AMP (X_{10}); the sand source to the AMP (X_{11}); the asphalt source to the AMP (X_{12}); the filler source to the AMP (X_{13}); and the volume of : the aggregate (X_{14}); the asphalt (X_{15}); and the asphalt mixture (X_{16}). The results of the stepwise analysis are presented in Table 10.

TABLE X
RESULTS OF THE STEPWISE ANALYSIS OF THE CASE STUDIES ON RIGID AND FLEXIBLE PAVEMENTS

Model	**Unstandardized coefficients**		**Correlation**	
	B	**Beta**	**partial**	**part**
Rigid Pavement				
(constant)	8658.01			
X_1	-317.70	-11.74	-0.172	-0.137
X_2	16.03	10.57	0.168	0.134
X_3	-14.03	-8.50	0.128	-0.102
X_4	7.39	2.36	0.143	0.114
X_8	12.36	10.23	0.159	0.127
Flexible Pavement				
(constant)	1397.07			
X_9	-33.63	-1.37	-0.17	-0.14
X_{10}	20.40	0.09	0.06	0.05
X_{12}	83.24	0.84	0.16	0.13
X_{13}	14.79	0.62	0.08	0.06

Based on the results of the analysis in Table 10, it was found that the dominant regression model formed for a large amount of greenhouse gas emissions on rigid pavements was:

$$Y_R = 8658.01 - 317.70X_1 + 16.03X_2 - 14.03X_3 + 7.38X_4 + 12.36X_8 \quad (2)$$

with an adjusted value of R^2 = 0.70. The significant predictors were the distance of the batching plant to the location of the project (X_1), the distance of the aggregate source to the batching plant (X_2), the distance of the sand source to the batching plant (X_3), the distance of the cement source to the batching plant (X_4), and the concrete volume (X_8). Based on the values of the correlations in Table 13, the shared and unique contributions of the significant predictors were X_1: $(0.172)^2 = 3.0\%$, $(0.137)^2 = 1.9\%$; X_2: $(0.168)^2 = 2.8\%$, $(0.134)^2 = 1.8\%$; X_3: $(0.128)^2 = 1.6\%$, $(0.102)^2 = 1.0\%$; X_4: $(0.143)^2 = 2.0\%$, $(0.114)^2 = 1.3\%$; X_8: $(0.159)^2 = 2.5\%$, $(0.127)^2 = 1.6\%$, respectively. The dominant regression model formed for greenhouse gas emissions on flexible pavements was:

$$Y_F = 1397.07 - 33.63X_9 + 20.40X_{10} + 83.24X_{12} + 14.79X_{13} \tag{3}$$

with an adjusted value of $R^2 = 0.62$. The significant predictors were the distance of the AMP to the location of the project (X_9), the distance of the aggregate source to the AMP (X_{10}), the distance of the asphalt source to the AMP (X_{12}), and the distance of the filler source to the AMP (X_{13}). Based on the values of the correlations in Table 13, the shared and unique contributions of the significant predictors were X_9: $(0.17)^2 = 2.9\%$, $(0.14)^2 = 2.0\%$; X_{10}: $(0.06)^2 = 0.3\%$, $(0.05)^2 = 0.3\%$; X_{12}: $(0.15)^2 = 2.3\%$, $(0.13)^2 = 1.7\%$; X_{13}: $(0.08)^2 = 0.6\%$, $(0.06)^2 = 0.4\%$, respectively.

C. Efforts to Reduce Greenhouse Gas Emissions

The unit processes that had the highest emissions of greenhouse gases were the production of cement and asphalt. Nevertheless, the results of the stepwise modeling on both the rigid and flexible pavements indicated that there was a reduction in the distance of the source of the pavement materials, especially the aggregate sources (X_2 and X_{10}), and these had the potential to reduce greenhouse gas emissions. Meanwhile, according to Santero and Gungat, greenhouse gas emissions can be reduced by using fewer natural resources or replacing or substituting them with less emissions-intensive materials [20]-[21]. Therefore, the greenhouse gas emissions reduction strategies, in this case, were to reduce the volume of materials and the distance for the transportation of the aggregates. The strategy to reduce the volume was implemented by using fly ash as a substitute for cement, while the use of asphalt was reduced by using recycled asphalt.

The simulation for the use of fly ash to reduce greenhouse gas emissions was based on the regulation on the maximum use of fly ash in Indonesia, which is 30%. Meanwhile, the percentage of recycled asphalt usage actually has no limits; the greater the use of recycled asphalt, the better it will be because the greenhouse gas emissions will be significantly reduced. However, in this research, it was taken as 10%, 20%, and 30%.

Table 11 shows a simulation of the reduction in greenhouse gas emissions due to the substitution of cement with fly ash for rigid pavements and the use of recycled asphalt for flexible pavements. Table 12 shows a simulation of the reduction in the percentage of greenhouse gas emissions due to a reduction in the percentage of the distance of the aggregate source. Table 11 indicates that a reduction of 10% in the volume of cement, which was replaced by fly ash, caused a decrease of 3.76-6.42% in greenhouse gas emissions. Each use of 10% of recycled asphalt caused a reduction of 3.62-5.45% in greenhouse gas emissions.

Table 12 indicates that a reduction of 10% in the transportation distance for the aggregates caused a decrease of 0.5-0.7% in greenhouse gas emissions. At reductions of 20%, 30%, 40% and 50% in the transportation distance for the aggregates, the reductions in greenhouse gas emissions were 1.0-1.3%, 1.4-1.9%, 1.9-2.6% and 2.4-3.2%, respectively. It might have been possible to simulate the reduction of the distance above 50%. The results, of course, would have shown a significant trend of decreasing greenhouse gas emissions. However, from the twelve case studies that were taken, apparently, the areas where the distance reduction was more than 50% were urban areas, whereas usually aggregate quarries are located in rural areas.

The use of recycled materials and materials from locations near the projects coincided with one of the sustainability criteria recommended by INVEST 2011 and Green road 2011 [22]-[23]. In order for the strategy to use recycled materials and materials near the project locations to be implemented during the construction phase, this strategy must be well-planned at the pavement design stage.

TABLE XI
GHG EMISSIONS RELEASED ON REDUCTION IN THE VOLUME OF CEMENT AND ASPHALT

Case study	**Percentage of GHG emission reduction (%)**		
	10%	**20%**	**30%**
Substitution fly ash semen on rigid pavement			
1	5.68	11.36	17.04
2	6.28	12.57	18.85
3	6.42	12.84	19.26
4	5.24	10.49	15.73
5	3.76	7.53	11.29
6	4.69	9.38	14.07
Asphalt recycle on flexible pavement			
7	5.28	10.57	18.85
8	5.45	10.91	16.36
9	4.81	9.61	14.42
10	4.71	9.43	14.14
11	3.77	7.55	11.32
12	3.62	7.24	10,85

TABLE XII
GHG EMISSIONS RELEASED ON REDUCTION IN THE DISTANCE OF AGGREGATE TRANSPORTATION

Case study	**Percentage of GHG emission release on distance reduction (%)**				
	10%	**20%**	**30%**	**40%**	**50%**
Rigid Pavement					
1	0.62	1.25	1.87	2.50	3.12
2	0.61	1.21	1.82	2.42	3.03
3	0.48	0.95	1.43	1.90	2.38
4	0.62	1.25	1.87	2.50	3.12
5	0.61	1.23	1.84	2.46	3.07
6	0.64	1.29	1.93	2.57	3.22
Flexible Pavement					
7	0.56	1.12	1.68	2.24	2.80
8	0.60	1.20	1.80	2.40	3.00
9	0.59	1.18	1.76	2.35	2.94
10	0.62	1.25	1.87	2.49	3.11
11	0.59	1.19	1.78	2.38	2.97
12	0.63	1.25	1.88	2.51	3.14

IV. CONCLUSIONS

From the analysis that was carried out in this research, it can be concluded that the critical point in the construction stage of rigid and flexible pavements was found to be in the processing of concrete and asphalt, which accounted for 56.6% and 45.4%, respectively of GHG emissions. In addition, in the rigid pavement activities, material processing, transportation, and construction contributed to 75.2%, 26.5%, and 3.1%, respectively of GHG emissions. In the case of flexible pavements, material processing, transportation, and construction contributed to 74.0%, 24.7%, and 2.3% of GHG emissions, respectively. From the results of the stepwise analysis on rigid pavements, it was known that the significant predictors were the distance of the batching plant to the project location (X_1); the aggregate source to the batching plant (X_2); the sand source to the batching plant (X_3); the cement source to the batching plant (X_4); and the concrete volume (X_8). In the flexible pavements, the significant predictors were the distance of the AMP to the project location (X_9); the aggregate source to the AMP (X_{10}); the asphalt source to the AMP (X_{12}), and the filler source to the AMP (X_{13}). The greenhouse gas emissions reduction strategy, in this case, was to reduce the material volume and the distance. A reduction of 10-30% in the volume of cement can reduce greenhouse gas emissions by 3.8-19.2%. Every reduction of 10% in the use of asphalt will reduce greenhouse gas emissions by an average of 4.6%. The average percentage of reduction in greenhouse gas emissions was 0.5-3.2% when the distance of the aggregate materials was reduced by 10-50%. As the construction industry in Indonesia has limited concerns with regard to the overall sustainability performance, a strategy should be implemented to raise awareness and improve construction works.

ACKNOWLEDGMENT

The authors would like to thank The Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the financial support through PDUPT research grand scheme.

REFERENCES

[1] F. S. Handayani, A. Setyawan, F. P. Pramesti, and M. A. Wibowo, "Strategy toward sustainable local road network infrastructure," in *Proc. EACEF 2017*, paper 07007, MATEC Web of Conferences 2017, p. 1-8.

[2] *The International Standards Organization, Environmental management — Life cycle assessment — Principles and framework.* ISO 14040, 2006.

[3] J. Y. Park, D. E. Lee, and B.S. Kim, "Development of environmental load-estimating model for road planning phase: Focus on road earthwork," *KSCE Journal of Civil Engineering,* vol. 22(2), pp. 459–466, 2018.

[4] N. Kokkaew, and J. Rudjanakanoknad, "Green assessment of Thailand's highway infrastructure: A Green Growth Index approach." *KSCE Journal of Civil Engineering*, vol. 21(7), 2526–2537, 2017.

[5] Y. Liu, Y. Wang, and D. Li, "Estimation and uncertainty analysis on carbon dioxide emission from construction phase of real highway project in China," *Journal of Cleaner Production,* vol. 144, pp. 337-346, 2017.

[6] X. Wang, Z. Duan, L. Wu, and D. Yang, " Estimation of carbon dioxide emission in highway construction: A case study in southwest region of China," *Journal of Cleaner Production,* vol.103, pp. 705-714, 2015.

[7] F. Ma, A. Sha, P. Yang, and Y. Huang, "The greenhouse gas emission from portland cement concrete pavement construction in China," *International Journal of Environmental Research and Public Health*, vol. 13. Pp. 632, 2016.

[8] A. Mulyana, and R.D. Wirahadikusumah, "Analysis of Energy Consumption and Greenhouse Gas Emissions in the Construction Phase Case Study: Construction of Cisumdawu Road," *Jurnal Teknik Sipil*, vol. 24(3), pp. 269–280, 2017.

[9] H. Li, D. Quanxue, Z. Jingxiao, O. O. Ayokunle, and L. Sainan, "Environmental impact assessment of transportation infrastructure in the life cycle: case study of a fast track transportation project in China,"*Energies,* vol. 12, 1015, pp. 1-15, 2019.

[10] R. O'Born, "Life cycle assessment of large scale timber bridges: A case study from the world's longest timber bridge design in Norway," *Transportation Research Part D: Transport and Environment*, vol. 59, pp. 301-312, 2018.

[11] S. Babaee, and D. H. Loughlin, "Exploring the role of natural gas power plants with carbon capture and storage as a bridge to a low-carbon future," *Clean Technologies and Environmental Policy,* vol. 20, pp. 379-391, 2018.

[12] D. Li, Y. Q. Wang, Y. Y. Liu, S. Feng, and D. W. Wang, "Estimating life cycle CO_2 emissions from freeway greening engineering," *ASCE-American Society of Civil Engineering: Reston,* pp. 796-805, 2018.

[13] "USEPA. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) Users Guide Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts," Cincinnati, 2012.

[14] Y. Huang, Y. Ning, T. Zhang, and J. Wu, "Measuring carbon emissions of pavement construction in China," *Sustainability,* vol. 8, 723, pp. 1-13, 2016.

[15] M. L. Marceau, M. A. Nisbet, and M. G. VanGeem, "Life Cycle Inventory of Portland Cement Concrete SN3011," Portland Cement Association, Skokie, Illinois, pp. 121, 2007.

[16] P. Zapata, and J. A. Gambatese, "Energy Consumption of Asphalt and Reinforced Concrete Pavement Materials and Construction," *Journal of Infrastructure Systems*, vol. 11(1), pp. 9–20, 2005.

[17] B. Hughes, and W. Hare, "LCI Data for Steel Product," Report World Steel Association, Brussels, Belgium, 2012.

[18] G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, "The ecoinvent database version 3 (part I): overview and methodology." *The International Journal of Life Cycle Assessment*, vol. 21(9), pp.1218–1230, 2016.

[19] L. Bushi, G. Finlayson, and J. A. Meil, "Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufacture by NRMCA Members," The Athena Sustainable Material Institute, pp. 36-39. 2014.

[20] N. Santero, A. Loijos, and J. Ochsendorf, "Greenhouse gas emissions reduction opportunities for concrete pavement," *Journal of Industrial Ecology*, Vol. 17, pp. 1-10, 2013.

[21] L. Gungat and M. O. Hamzah, "Green road construction using reclaimed asphalt pavement with warm mix additive," *International Journal on Advanced Science Engineering Information Technology,"* vol. 8, pp. 426-430, 2018.

[22] *Vicroads. Integrated Vicroads Environmental Sustainability Tool (INVEST), Vicroads Environmental Sustainability*. Federal Highway Administration, Washington DC: FHWA, 2011.

[23] S.T. Muench, J.L. Anderson, J. P. Hatfield, J. R. Koester, and M. Soderlund, et al., *Greenroads Manual v1.5* (J.L. Anderson, C.D. Weiland, and S.T. Muench, Eds.), Seattle, WA: University of Washington, 2011.