Measuring Carbon Footprint of Flexible Pavement Construction Project in Indonesia

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Abstract. Road infrastructure in Indonesia is mainly dominated by flexible pavement type. Its construction process, however, has raised concerns in terms of its environment impacts. This study aims to track and measure the carbon footprint of flexible pavement. The objectives are to map the construction process in relation to greenhouse gas (GHG) emissions, to quantify them in terms of carbon dioxide equivalents (CO_2e) as generated by the process of production and transportation of raw materials, and the operation of plant off-site and on-site project. Data collection was done by having site observations and interviews with project stakeholders. The results show a total emissions of 70.888 tonnes CO_2e, consisting of 34.248 tonnes CO_2e (48.31%) off-site activities and 36.640 tonnes CO_2e (51.687%) on-site activities. The two highest CO_2e emissions were generated by the use of plant for asphalt concrete laying activities accounted 34.827 tonnes CO_2e (49.130%), and material transportation accounted 24.921 (35.155%). These findings provide a new perspective of the carbon footprint in flexible pavement and suggest the urgent need for the use of more efficient and environmentally friendly plant in construction process as it shows the most significant contribution on the CO_2e. This study provides valuable understanding on the environmental impact of typical flexible pavement projects in Indonesia, and further can be used for developing green road framework.

1 Introduction

The construction industry is one of important sectors in national infrastructure development. While it supports national economy, a series of construction activities is potentially harmful to the environment. In 2010, the construction sector contributed 18% directly or indirectly to greenhouse gas emissions [1]. In 2007, China's construction sector accounted for nearly 50% of total energy use in which major energy–producing contributors were; materials, heating, fuels, and electricity supply [2]. As the largest CO_2 emitter since 2013 China's emissions even showed an upward trend as a quadratic polynomial [3].

One of the construction sectors that produce significant greenhouse gas emissions is road construction, which will continue to increase along with the growth of the road length built by the government. Road infrastructure in Indonesia is dominated by flexible pavement which allegedly produces high greenhouse gas emissions due to changes in land conditions and functions, and the consumption and exploitation of resources. This is in line with a study in the Netherland which compared emissions from different types of pavement and that found that flexible pavement emits carbon emissions higher than rigid pavement and brick roads mostly from production and construction activities [4]. Life cycle assessment on flexible pavement construction activities showed that it generated twice higher carbon emissions than that of rigid pavement construction activities [5].

The carbon emissions have been closely linked to global warming and will leave carbon footprint. Although it has now become one of main environmental indicators [6], however it has been defined differently, e.g. [7-11]. One of the most cited common definitions of Carbon footprint is; a measure of the whole sum of CO_2 emissions resulted directly or indirectly from activities of individual, organization, process, industry sectors over the life cycle of a product (goods and services) [12]. The importance of relating the environmental aspects, in terms of energy consumption and carbon emissions, with the decision of pavement design has been promoted as opposed to typically cost consideration [13].

This study aims to track and measure the carbon footprint of flexible pavement construction. The objectives are to map the construction process in relation to greenhouse gas (GHG) emissions, to quantify the GHG emissions in terms of carbon dioxide equivalents (CO_2e) as generated by the process of production and distribution of raw materials, and the operation of plant in the project.

2 Highway Pavements

The highway pavement is a section of highway which is hardened by a certain construction layer. It has a certain

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thickness, strength, and stiffness, and stability in order to be able to channel the traffic load on it to the ground safely. Other factors, such as environmental condition, temperature, seepage and properties of materials also influence the behaviour of the pavement [14].

Flexible pavement is one type of road pavement that uses asphalt as a binder. Typical layers of flexible pavement include sub-grade, sub-base, and base courses, binder course, and surface course and have the function to carry and transfer traffic loads to the sub-grade (Fig. 1). Based on temperature during mixing and compacting, asphalt concrete is divided into hot mix, warm mix, and cold mix. This study focuses on hot mix asphalt concrete as it is the most commonly works method and is considered to meet pavement requirements. A typical cross section of the flexible pavement is shown in Fig. 2.

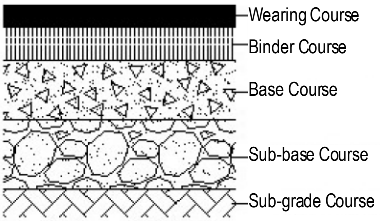

Fig. 1. Typical layers of flexible pavement

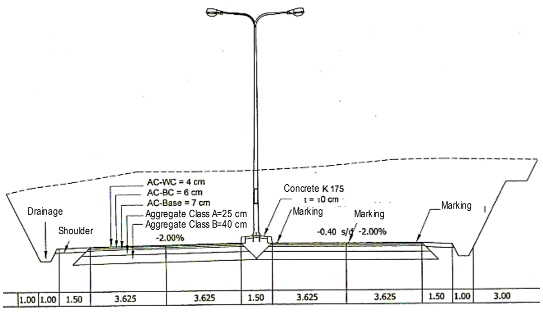

Fig. 2. Cross-section of the flexible pavement

3 Construction Method of Flexible pavement

The stages of flexible pavement work include preparatory work, sub base and base course work, and surface course work. Preparatory work related to the survey, and preparation of body of the road. Sub-base and base work include spreading work using grader, and compaction work using roller and worked after the sub-grade meets the elevation and density requirements.

Surface course work includes prime coat work, and asphalt concrete work using asphalt finisher, dozer, and pneumatic tired roller. Table 1 shows the sequence of works of a flexible pavement project as observed from Salatiga Ring Road project from STA. 9 + 285 to STA. 9 + 385.

Table 1. Sequence of work of typical flexible pavement

No	Sequence of Work	Description
1	Sub-base Course	Mixing and loading the aggregate in a Dump Truck using Wheel Loader in Base Camp. Transporting aggregate to the job site by Dump Truck and overlaid it using Motor Grader. Overlay aggregate wetted with Water Tank Truck before compacted using Tandem Roller and pneumatic tandem roller. During compacting, a group of workers will tidy up the edge of the expanse and surface level using a tools.
2	Base Course	Wheel Loader mixes and loads aggregate into Dump Truck in Base Camp. Dump truck transports aggregate to the job site and overlaid it with Motor Grader. Overlay aggregate wetted with Water Tank Truck before compacted using Tandem Roller and Pneumatic Tandem Roller. During compacting,, a group of workers will tidy up the edge of the expanse and surface level using a tools.
3	*Asphalt Concrete-Base*	Wheel Loader loads aggregate into asphalt mixing plant's (AMP) Cold Bin. Aggregates and asphalts are mixed and heated by AMP and to be loaded directly into the Dump Truck and transported to the job site. The AC-Base hot mix is overlaid by Finisher and compacted by Tandem Roller and Pneumatic Tandem Roller. During compacting,, a group of workers will tidy up the edge of the expanse and surface level using a tools.
4	*Asphalt Concrete - Base Course*	Wheel Loader loads aggregate into AMP's Cold Bin. Aggregates and asphalts are mixed and heated by AMP and to be loaded directly into the Dump Truck and transported to the job site. The AC-BC hot mix is overlaid by Finisher and compacted by Tandem Roller and Pneumatic Tandem Roller. During compacting,, a group of workers will tidy up the edge of the expanse and surface level using a tools.
5	*Asphalt Concrete – Wearing Course*	Wheel Loader loads aggregate into AMP's Cold Bin. Aggregates and asphalts are mixed and heated by AMP and to be loaded directly into the Dump Truck and transported to the job site. The AC-Wearing Course hot mix is overlaid by Finisher and compacted by Tandem Roller and Pneumatic Tandem Roller. During compacting,, a group of workers will tidy up the edge of the expanse and surface level using a tools.

4 Carbon Emissions of Construction Resources

In the construction industry the CO_2 emission varies along the project life cycle, however the density of the CO_2 emissions is the highest in construction phase compared to operation and maintenance phases [15, 16]. Construction materials and the use of plant during construction phase have the potential to generate greenhouse gas emissions through the exploitation of materials in nature, and the use of fossil fuels during the production process. Plant refers to all heavy machinery and equipment utilised for construction works.

According to the Kyoto Protocol 2007 [17], there are six main greenhouse gases, namely carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PHCs) and sulphur hexafluoride (SF6). Internationally, the effect size of a process on the environment is gas emissions equalized with CO_2 equivalent (CO_2e). CO_2e emission conversion factors generated by material production and the use of fossil fuels are presented in Table 2.

Table 2. CO_2 equivalent emission conversion factors [18, 19]

No	Resources	Emission Factor	Source
Materials			
1	Coarse aggregate	1.067 kg CO_2/ ton	US EPA, 2004
2	Fine aggregate	1.067 kg CO_2/ ton	US EPA, 2004
3	Filler	1.067 kg CO_2/ ton	US EPA, 2004
4	Asphalt	11.91 kg CO_2/ gal	Climate Registry Default Emission Factor, 2016
Fossil fuels			
1	Motor gasoline	2.32 kg CO_2/ liter	US EPA, 2004
2	Diesel fuel	2.66 kg CO_2/ liter	US EPA, 2004
3	LPG (HD–5)	1.52 kg CO_2/ liter	US EPA, 2004

Carbon footprint can be classified as embodied carbon (EC) and operational carbon (OC) [20]. EC is emissions resulted from the production, transportation and construction stages. OC is carbon emissions resulted from the utilization of built facilities, which is normally believed to be higher than the EC. However, estimating the EC values are challenging due to variability of project characteristics, e.g. construction type, design, site condition, etc.

The carbon footprint measurement in this study covers off-site and on-site project activities (Fig. 3). Off-site activities include material production and transportation, while onsite activities examine the operation of plant use for asphalt concrete production and laying for road sub-base, base, and surface courses. The material production includes the processing of natural materials, such as coarse aggregate and fine aggregate, fillers and asphalt. Material transportation generates carbon emissions by bringing the natural materials from the sources to project site, using dump trucks for aggregate and filler, and tank truck for asphalt. The production of asphalt concrete operates AMP and wheel loader. While for asphalt concrete laying more plant were used, such as dump truck, motor grader, vibrator roller, water tanker, etc.

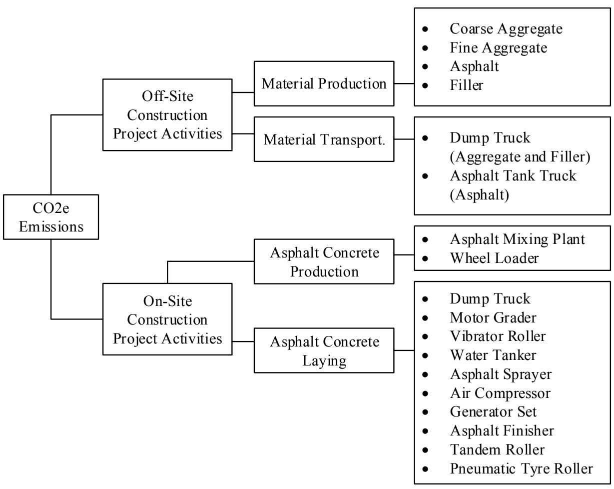

Fig. 3. Sources of carbon emissions of typical flexible pavement project

5 Research method

The object of this study is Salatiga Ring Road project from STA. 9 + 285 up to STA. 9 + 385 with four 3.625-meter-width lanes and flexible pavement type (Fig. 2) Data collection was done by having regular site observations to flexible road projects, interviews with project stakeholders, as well as document analysis. Site observation was carried out to understand the construction methods (see Table 1), procedure, including the materials and equipment used in the project. Interview with project staffs enhanced the understanding the common practice in the typical projects.

The method of this study is a case study method carried out by quantifying the CO_2e emissions generated during the construction of flexible pavement including material production and transportation, and the plant operation. Material production stage includes the amount of CO_2e emissions associated with the mining, processing, and production of materials construction. Material transportation stage includes the amount of CO_2e emissions associated transportation of construction materials from the source or manufacture to the site. Plant use stage includes the amount of CO_2e emissions associated with the fuels consumption during the construction of sub base and base course, and surface course. Data analysis techniques of this study is quantitative analysis by multiplying each factor causing CO_2 emissions in construction with emission factor as presented in equations 1, 2, and 3.

$$CO_2e_{MP} = V \text{ x } EF_{MP} \quad (1)$$

$$CO_2e_{MT} = TFC_{MT} \text{ x } EF_{MT} \quad (2)$$

$$CO_2e_{PU} = TFC_{PU} \text{ x } EF_{PU} \quad (3)$$

where CO_2e_{MP}, CO_2e_{MT}, CO_2e_{PU} denote the carbon emissions equivalent for material production, material transportation, and plant use, respectively (ton CO_2e). V denotes the volume of materials. EF_{MP}, EF_{MT}, and EF_{PU} denote the emission factor for material production (kg CO_2/ton), material transportation (kg CO_2/litre), and plant use (kg CO_2/ litre), respectively. TFC_{MT} and TFC_{PU} denote Total Fuel Consumption (litre) for material transportation and plant use, respectively.

6 Results and analysis

6.1 CO_2e emissions from off-site construction project activities

6.1.1 CO_2e Emissions of Material Production

For material production, the CO_2e emission is calculated by multiplying the volume of each material with emissions factor as presented in Table 3. The total CO_2e emission in material production for all road layers is 9.327 tonnes CO_2e. Asphalt contributes the highest CO_2e of 7.564 tonnes CO_2e, followed by coarse aggregate contributes of 1.247 tonnes CO_2e, fine aggregate contributes of 0.515 tonnes CO_2e, and filler contributes 0 tonnes CO_2e (Fig. 4).

Table 3 The CO_2e emissions in material production

No	Components	Materials	Volume (Kg)	Emissions Factor kg CO_2 / ton	Total Emissions (Tonnes CO_2e)
(1)	(2)	(3)	(4)	(5)	(6) = (4) x (5) / 1000
1	Subbase course (t=15 cm)	Coarse agg.	609	1.067	0.650
		Fine agg.	203	1.067	0.217
2	Base course (t=15 cm)	Coarse agg.	380.625	1.067	0.406
		Fine agg.	126.875	1.067	0.135
3	Prime coat	Asphalt	1.951	11.91	5.924
4	Tack coat	Asphalt	0.525	11.91	1.595
5	AC – Base (t=6 cm)	Coarse agg.	73.892	1.067	0.079
		Fine agg.	53.998	1.067	0.058
		Filler	0.004	1.067	0.000
		Asphalt	0.006	11.91	0.019
6	AC – Base course (t=6 cm)	Coarse agg.	60.9	1.067	0.065
		Fine agg.	70.644	1.067	0.075
		Filler	0.005	1.067	0.000
		Asphalt	0.006	11.91	0.017
7	AC– Wearing course (t=4 cm)	Coarse agg.	44.66	1.067	0.048
		Fine agg.	28.42	1.067	0.030
		Filler	0.002	1.067	0.000
		Asphalt	0.003	11.91	0.010
		Total			9.327

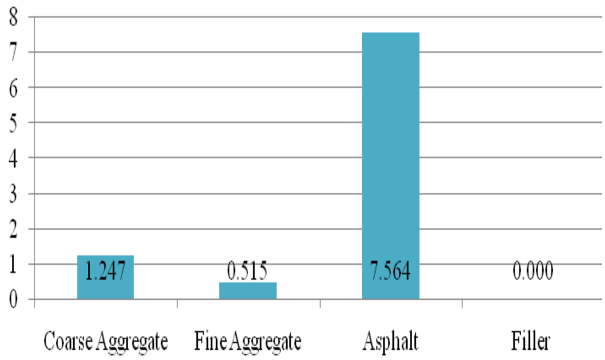

Fig. 4. CO_2e emissions of material production

The main constituent materials of flexible pavement are asphalt and coarse aggregate. Asphalt production has a long production process of petroleum distillation residue and has an emission factor of 11.91 kg CO_2 / gal [19]. Whereas, the aggregate production process is generated by the volcanic working mechanism so that it has a smaller emissions factor of 1.067 kg CO_2/ ton [18]. The differences in production process and in the value of the emission factor affect the total emissions generated by each of the flexible pavement constituent materials.

6.1.2 CO_2e Emissions of Material Transportation

For material transportation, the CO_2e emission is calculated by multiplying the total of fuel consumption associated material transportation with emissions factor as presented in Table 4. With a total CO_2e emission of 24.921 tonnes CO_2e, fine aggregate contributes the highest CO_2e emission (18.876 tonnes CO_2e), followed by coarse aggregate (5.712 tonnes CO_2e), asphalt (0.306 tonnes CO_2e), and filler (0.027 tonnes CO_2e). The distance between the fine aggregate source and the AMP is very far (i.e. 201 km), and the large demand of fine aggregate affects total fuel consumption and the release of CO_2e emissions.

Table 4 CO_2e emissions in material transportation

No	Mat	Vol	CoP	DfS (km)	TD (km)	TFC (liter)	TE (Tonnes CO_2e)
1	Coarse agg.	835.055 m^3	4 m^3	18	7515	2147.284	5.712
2	Fine agg.	344.955 m^3	4 m^3	144	24837	7096.217	18.876
3	Asphalt	2392.5 liter	13200 liter	201	402	114.857	0.306
4	Filler	0.008 m^3	4 m^3	18	36	10.286	0.027
				Total			24.921

Note : CoP = Capacity of plant, DfS= Distance from source (km),
TD = Total Distance [DfS*Vol/CoP*2], TFC=Total Fuel Consumption = TD*0.126 [Diesel = 0.286 l/km], TE= Total Emission = TFC*2.66/1000 [Diesel = 2.66 kgCO_2/litre]

6.2 CO_2e emissions from on-site construction project activities (asphalt concrete production and laying)

The CO_2e emissions in terms of plant operation are released during the process of compaction and asphalting. The CO_2e emissions is calculated by multiplying the total of fuel consumption associated plant use in construction site and AMP with emissions factor as presented in Table 5. It shows the total CO_2e emission related to the plant operation is 36.64 tonnes CO_2e.

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Tabel 5 CO_2e emissions for plant operation on on-site

No	Components	Vol. (m^3)	Units	Plants	Plant Coef. (hour/m^3)	Operati-onal Time (hour)	Fuel Consump / hour (gal/hour)	Total Fuel Consump (litre)	Total Emissions (Tonnes CO_2e)
(1)	(2)	(3)	(4)	(5)	(6)	(7) = (3) x (6)	(8)	(9) = (7) x (8) x 3.79	(10) = (9) x 2.66 / 1000
1	Sub base course (t = 15 cm)	580	m^3	Wheel Loader	0.061	35.380	2.08	278.908	0.742
				Dump Truck	0.292	169.418	5.50	3531.518	9.394
				Motor Grader	0.011	6.612	6.00	150.357	0.400
				Vibro	0.017	10.092	10.50	401.611	1.068
				Water Tanker	0.021	11.948	5.00	226.415	0.602
2	Base course (t = 15 cm)	362.5	m^3	Wheel Loader	0.061	22.112	2.08	174.317	0.464
				Dump Truck	0.292	105.886	5.50	2207.199	5.871
				Motor Grader	0.011	4.132	6.00	93.973	0.250
				Vibro	0.017	6.308	10.50	251.007	0.668
				Water Tanker	0.021	7.468	5.00	141.509	0.376
3	Prime coat	1885	liter	Asph. Sprayer	0.335	0.631	0.26	0.631	0.002
				Air Compress	0.000	5.613	1.50	31.910	0.085
4	Tack coat	507.5	liter	Asph. Sprayer	0.335	0.170	0.26	0.170	0.000
				Air Compress	0.000	5.613	1.50	31.910	0.085
5	AC – Base (t = 6 cm)	101.5	m^3	Wheel Loader	0.048	4.842	2.08	38.167	0.102
				AMP	0.054	5.491	4.00	83.246	0.221
				Genset	0.054	5.491			
				Dump Truck	1.329	134.934	5.50	2812.701	7.482
				Asph. Finish	0.068	6.861	8.52	221.623	0.590
				Tandem Roll	0.028	2.842	4.00	43.085	0.115
				Pneumatic Tyre Roller	0.021	2.121	4.00	32.160	0.086
6	AC – Base Course (t = 6 cm)	87	m^3	Wheel Loader	0.048	4.150	2.08	32.714	0.087
				AMP	0.054	4.707	4.00	71.354	0.190
				Genset	0.054	4.707			
				Dump Truck	1.392	121.139	5.50	2525.138	6.717
				Asph. Finish	0.068	5.881	8.52	189.963	0.505
				Tandem Roll	0.028	2.436	4.00	36.930	0.098
				Pneumatic Tyre Roller	0.021	1.818	4.00	27.565	0.073
7	AC – Wearing Course (t = 4 cm)	58	m^3	Wheel Loader	0.002	0.110	2.08	0.869	0.002
				AMP	0.002	0.122	4.00	1.846	0.005
				Genset	0.002	0.122			
				Dump Truck	0.105	6.113	5.50	127.430	0.339
				Asph. Finish	0.003	0.151	8.52	4.871	0.013
				Tandem Roll	0.002	0.093	4.00	1.407	0.004
				Pneumatic Tyre Roller	0.002	0.128	4.00	1.934	0.005
				Total					36.64

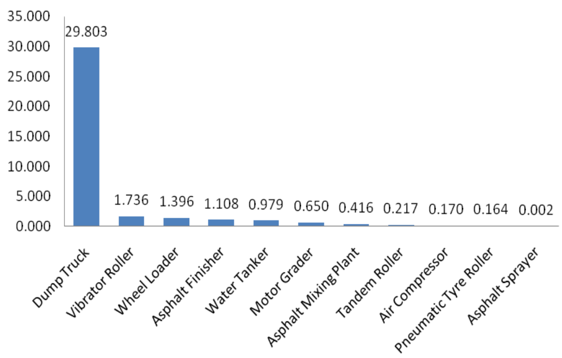

Fig. 5. CO_2e emissions for each type of plant

Figure 5 shows that operation of dump trucks contributes the highest CO_2e emissions of 29.803 tonnes CO_2e, which leaves a significant gap compared with other types of plant.

The great volume of asphalt as well as great distance from AMP to site (approximately 80 km) have great impact on the fuel consumption, which linked to significant CO_2e emissions emitted.

7 Discussions

Table 6 summarizes the results of the research that the total emissions of this project is 70.888 tonnes CO_2e. It can be seen that the highest CO_2e emissions were generated by the use of plant for on-site activities 36.640 ton CO_2e (51.687%), particularly for asphalt concrete laying activities accounted 34.827 (49.130%). The CO_2e emission of material transportation is the second highest accounted 24.921 (35.155%). Both asphalt concrete laying activities and material transportation indeed operate plant, particularly dump trucks, intensively during construction works, which obviously will generate significant amount of CO_2e. This condition is worsened by the great distance to transport materials (fine aggregate) from the quarry to project site, and asphalt from the AMP location to project site.

Table 6. Summary of CO_2e emission of Flexible Pavement

CO_2e emission off-site project (ton CO_2e)		CO_2e emission on-site project (ton CO_2e)		Total CO_2e emissions (ton CO_2e)
Material production	**Material Transport**	**Asphalt Concrete production**	**Asphalt Concrete Laying**	
9.327 (13.157 %)	24.921 (35.155 %)	1.813 (2.557 %)	34.827 (49.130 %)	70.888
34.248 (48.313 %)		36.640 (51.687 %)		

In this context, where great distance of transporting materials contributes significantly to the amount of CO_2e emissions, it is very important to manage plant and resource allocation to get optimum results. The AMP should be located as near as possible to the site to reduce time travel as well as reducing the carbon emissions. Closer distance will also minimize risks of travelling, such as traffic jam, accident, while at the same time maintaining the quality of hot asphalt from the AMP. In addition, with the significant contribution of plant operation of carbon emissions, there is also an urgent need for the use of more efficient and environmentally friendly plant in the construction process.

As coarse and fine aggregates are dominant materials in the flexible pavement, the use of recycled materials is one option to reduce the amount of energy and carbon emissions. Recycling will minimize the need for material extraction from nature, processing and production which eventually will contribute to reducing carbon emissions. This has been addressed by several studies, e.g. [21-23].

The results of this research provide a new perspective in comparison to the results of a study in China [24]. Using similar method to estimate carbon emissions from construction steps, i.e. production of materials, transportation of materials, and on-site construction activities, they found that most CO_2e emissions (over 80%) were contributed by production of raw materials. On-site activities and transporting materials generated only 10% and 3% of the total CO_2 emissions. While Wirahadikusuma et al [25] found that aggregate drying process at the AMP contributed most on energy consumption (68%) and carbon emissions (70-75%).

As each project is unique, the difference can be caused by distance of sources of materials, types of plant used, construction method, site condition, etc. These factors may explain why various results may be obtained from various researches. Nonetheless, the findings of this research provides a new perspective of the carbon footprint in flexible pavement in Indonesia, and suggest opportunities for developing research areas related to road pavement technology which is more environmentally friendly. On top of that, the use of more efficient plant, recycled materials, and better management will help reducing carbon emission from the construction sector to tackle global warming.

8 Conclusions

This research has successfully tracked and measured the carbon footprint of flexible pavement, using Salatiga Outer Ring Road STA. 9 + 285 to STA. 9 + 385 with four 3.625-meter-width lanes as the case study. The total emissions of this project is 70.888 tonnes CO_2e, consisting of 34.248 tonnes CO_2e (48.31%) off-site activities and 36.640 tonnes CO_2e (51.687%) on-site activities. The two highest CO_2e emissions were generated by the use of plant for on-site activities for asphalt concrete laying activities accounted 34.827 tonnes CO_2e (49.130%), and material transportation accounted 24.921 (35.155%).

The findings of this research provide new information and portray pictures of carbon footprint sources and quantification model of carbon emissions in flexible pavement project. It has also provided a case study which may help stakeholders including government in formulating policies for national green road development. To gain more comprehensive understanding on the carbon footprint, it is recommended for future research to include also emissions at the operational and maintenance stages, as well as sub grade compaction work. In addition, as one case study may have limitation for generalization, more number of flexible pavement projects may provide more evidence and more comprehensive results.

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