

Estimating carbon emission of rigid pavement: a case study of Palur Flyover

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Abstract. All construction activities will inevitably produce CO₂ emissions from the production process of materials, transportation, the usage of plant and equipment, the construction process, up to building demolition. Therefore, it is very important to understand the construction process and the amount of CO₂ emissions released at each stage of the construction process. This research aims to estimate the amount of CO₂ emissions during the construction process of a rigid pavement project. Data collection is done by observing rigid pavement of Palur Flyover project as a case study. The results show the total CO₂ emissions during the construction process equals 92.901 tonnes CO_{2e}, consisting of 91.334 tonnes CO_{2e} (98.3%) of off-site activities, and 1.567 tonnes CO_{2e} (1.7%) of on-site activities. The highest emission from off-site activities coming from material production of cement and steel rebars of 88.166 tonnes CO_{2e} (94.9%), and the material transportation process of 3.168 tonnes CO_{2e} (3.4%). This research shows that off-site construction activities, i.e. material production and transportation significantly influence the extent of CO₂ emissions in this rigid pavement project. Therefore, it is recommended that strategic efforts for reducing the CO₂ emissions of other typical rigid pavement projects should focus on these two.

1 Introduction

Global warming has been considered as a real threat to the world. Not only it has a negative effect on living things, but also could damage the environment sustainability. Environmental pollution has been considered as the main contributors to the global warming. There are various types of environmental impact indicators, such as greenhouse gas (GHG) traces, eutrophication potential (EP), acidification potential (AP), human health particles (HH), ozone depletion, and haze [1]. The environmental pollution has also been considered as a major challenge in the construction industry.

Based on data from the USA, the construction projects are accounted 39% of CO₂ gas emissions. It is far greater than the transportation field and industry [2], while data from the European Union mentioned 11% of CO₂ emissions [3] and 18.1% in Australia [4]. The

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construction process has a significant impact on the degradation of environmental quality. One of the construction processes that produce relatively large CO₂ emissions is road construction project. The CO₂ emission originates from the energy released during the life cycle of the construction project, starting from the production stage, the construction stage, the operational stage, and the demolition stage [5]. Therefore, it is necessary to apply the principle of sustainable development with a green construction perspective. The concept of green construction means environmentally friendly construction through work methods, usage of materials, usage of construction equipment, management, and supervision [6].

The adoption of green construction that implements environmentally friendly construction on an infrastructure project is known as green infrastructure. Green infrastructure is a natural and semi-natural area network, strategically planned with other environmental features, designed, and managed to provide a variety of eco-systemic services and benefits [7]. The application of green infrastructure concept in road projects is known as green road. Green road is a standard to measure sustainable development practices related to road design and construction. Green road is a system which is expected to improve accessibility and mobility, maintain, protect, and improve the performance system, as well as the environment in the project location [8].

The evaluation of environmental impacts due to CO₂ emissions from road construction, rehabilitation, and operations has become an important issue, and a global concern [9]. This evaluation is done by tracking and measuring carbon levels in each activity. A study on a highway construction project in Michigan used the Project Emission Estimator tool in estimating and calculating carbon footprints [10]. A project in India developed a computer program toolkit (Carbon Footprint Calculator) to measure the carbon footprint of various pavement systems [11]. Some research on carbon footprints on road projects is mostly dominated at the stage of material production and construction. A study on one of the road projects in the US mentioned that, surfacing roads using asphalt has higher emission level of 6730 CO_{2e} (tonnes) than concrete of 3872 CO_{2e} (tonnes), and overlay using asphalt of 5598 CO_{2e} (tonnes) [12]. Considering the unique characteristic of every construction project, the research results may vary among the different projects. The aim of this study is to estimate the total CO_{2e} emissions during the construction process of a rigid pavement project.

2 Road construction

Roads are lines of lands on earth made by humans with various shapes, sizes, and types of construction as the path for people, animals, and vehicles that transport goods from one place to another easily and quickly [13]. Typically, rigid pavement consists of three layers, i.e. concrete slab, subbase course and subgrade (figure 1). Unlike the flexible pavement, the rigid pavement is not made continuously along the road. This is done to prevent large expansion on the pavement surface which can cause some cracks, and to prevent continuous cracking if there is a crack at one point on the pavement [14]. Another way of prevention is by constructing a joint system to connect each segment of the rigid pavement. There are three joint systems, i.e. jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). Typical rigid pavement construction is shown in Figure 1.

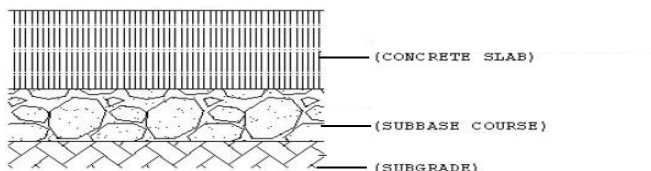


Fig. 1. Typical Rigid Pavement Components

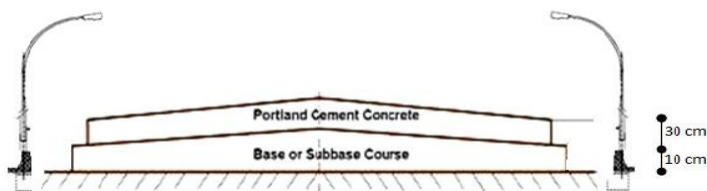


Fig. 2. Typical Cross Section of Rigid Pavement

2.1 Construction of rigid pavement

Some heavy equipment is needed for constructing the rigid payment, e.g. excavators, bulldozers, vibrating rollers, dump trucks, mixer trucks, etc. The biggest use of heavy equipment is usually in the process of quarrying and layering the road foundation. For the next process, even though the use of heavy equipment is not as much as at the stage of quarrying, the equipment will be used mainly for handling a larger volume of materials, especially cement and aggregate.

In the rigid pavement construction stage, the sequence of work starts from concrete leaning, formwork installation, geotextile installation, rebar installation, casting, grooving, and cutting.

Table 1. Work Sequence of Rigid Pavement

No	Work Sequence	Description
1	Concrete Leaning	a. Cement, Fly Ash, Coarse Aggregate, Fine Aggregate, Water, <i>Plastiment-Vz</i> (type D), <i>Naphoplast</i> (type F) are loaded and mixed into Batching Plant. b. The concrete mix is loaded into <i>Truck Mixer</i> and then transported to the project site. c. The concrete mix is unloaded and then spread out by the worker using the special tool.
2	Formwork Installation	Formwork installation on lean concrete
3	Geotextile Installation	Geotextile installation on lean concrete
4	Rebar Installation	a. Installing transverse reinforcement, longitudinal reinforcement, tie bars, and dowel according to the shop drawing. b. Tying the rebar with rebar tie wire so that the rebar will not shift during the casting. c. The dowel's ends are blunted and varnished using vaseline & plastic, so that it will lose with the concrete and sliding well. d. The centre of the tie bar is varnished with anti-rust paint.

5	Casting	<ol style="list-style-type: none"> Cement, Fly Ash, Coarse Aggregate, Fine Aggregate, Water, Plastiment-Vz (type D), Naphoplast (type F) are loaded and mixed into Batching Plant. The concrete mix is loaded into <i>Truck Mixer</i> and then transported to the project site. The concrete mix is unloaded and compacted with concrete vibrator then spread out evenly by the special tool.
6	Grooving and Cutting	<ol style="list-style-type: none"> Grooving the surface so that the surface will not be slippery. Cutting the concrete on the expansion joint. Applying joint sealer on the expansion joint.

The production process of each material is different, thus the CO₂ emissions produced will be different as well, depending on how much the volume of materials needed in the construction process. The conversion factors for CO₂ emissions caused during the construction process are shown in the table 2.

Table 2. Factor of CO₂ Emission Conversion

No	Material	Conversion Factor	Source
Material			
1	Steel Rebar	2.4-ton CO ₂ /ton	[15]
2	Cement	1-ton CO ₂ /ton	[15]
3	Coarse Aggregate	1.067 kg CO ₂ /ton	[16]
4	Fine Aggregate	1.067 kg CO ₂ /ton	[16]
5	Fly Ash	1.067 kg CO ₂ /ton	[16]
Fuel			
1	Motor Gasoline	2.32 kg CO ₂ /litre	[16]
2	Diesel Fuel	2.66 kg CO ₂ /litre	[16]
3	LPG (HD-5)	1.52 kg CO ₂ /litre	[16]

The scheme of estimating CO₂ equivalent emissions (CO_{2e}) used in this study is shown in figure 3. The emissions are reviewed based on off-site and on-site activities. The off-site activities include the production stage of materials, such as cement materials, fine aggregates, coarse aggregates, fly ash/fillers, and rebar, and the transportation of materials, includes emissions from transporting vehicles, such as dump trucks and cement trucks. The on-site activities include the concrete production and concrete laying stages. The production of concrete utilizes batching plant, generators and truck mixers, while the concrete laying uses some equipment such as concrete vibrators, concrete cutters, and generators.

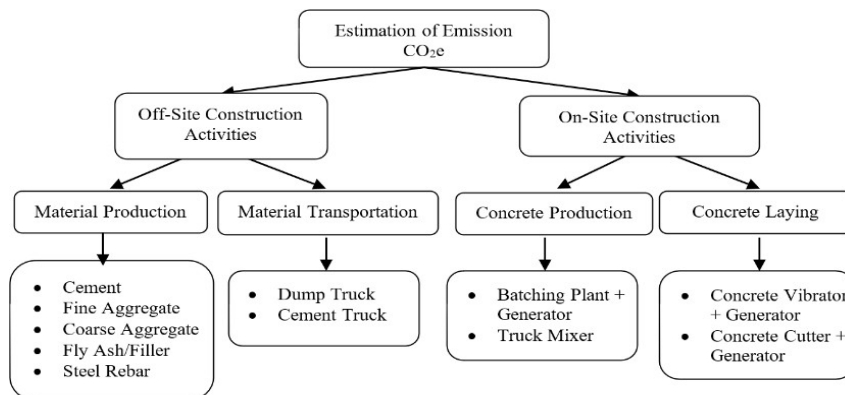


Fig. 3. Calculation Concept of CO_{2e} Emission on Rigid Pavement Project

3 Research methods

This research used the rigid pavement of Palur Flyover project as a case study to estimate the amount of CO_{2e} gas emissions generated during the construction of the rigid pavement. The project was located in the border of Surakarta - Palur (Karanganyar), with the road section being reviewed was STA. 0 + 350 to 0 + 450 (100 m) with 2 lanes of a 3 m width, and areas of 600 m².

Data was obtained by site observation and interview with contractor personnel on site, e.g. site manager, logistic managers, heavy equipment operators, etc. Observation was made on the carbon footprint during the rigid pavement construction process, including levelling concrete, rebar installation, and casting process. Data obtained from observations include stages of the rigid pavement process, heavy equipment usage and their respective capacities, as well as any other variables that cause CO₂ gas emissions in the process. While interviews were conducted to find out the amount of fuel consumption of each heavy equipment and as well as to identify where the materials come from.

The formulas in equations 1, 2, and 3 are used for estimating the amount of CO₂ emissions produced by each activity.

$$ECO_{2ePM} = V \times FC_{PM} \quad (1)$$

$$ECO_{2eTM} = TFC_{TM} \times FC_{TM} \quad (2)$$

$$ECO_{2ePA} = TFC_{PA} \times FC_{PA} \quad (3)$$

The ECO_{2ePM} , ECO_{2eTM} , and ECO_{2ePA} are the total of CO_{2e} gas emissions in material production activities, material transportation, and heavy equipment usage on construction site, in units of tonCO_{2e}. The volume of material (V) is calculated based on the amount of material needed during the construction activities, both at the material production stage and the construction stage. FC_{PM} , FC_{TM} , FC_{PA} are CO₂ emission conversion factors according to the types of sources, such as materials and fuel. As for the conversion factor of material production (PM), unit in kgCO₂/ton is used, while unit of kgCO₂/litre is used for transportation materials (TM), and kg CO₂/litre is used for heavy equipment on the construction site (PA). TFC_{TM} and TFC_{PA} are the total fuel consumption used in the material transportation and the use of heavy equipment during construction.

4 Results and analysis

This section explains the results and analysis of the estimate CO_{2e} emissions from the off-site and on-site construction activities.

4.1. Off-site construction activities

4.1.1. CO_{2e} emissions in material production

CO_{2e} emissions produced during the construction process are caused by material production, material transportation, and the use of heavy equipment. Table 3 shows the calculation of CO_{2e} emissions caused by the production process of the materials of the rigid pavement.

Table 3. Equivalent CO₂ Emissions Based on Material Production Processes

No	Component	Materials	Volume (ton)	Conversion Factors	CO ₂ e Emission (ton)
(1)	(2)	(3)	(4)	(5)	(6)=(4)x(5)
1	Levelling concrete t = 10 cm	Cement	8.940	1ton CO ₂ /ton	8.940
2	Rigid Pavement t = 30 cm	Cement	71.100	1ton CO ₂ /ton	71.100
		Steel Rebars	3.386	2.4ton CO ₂ /ton	8.126
Total					88.166

It is found that cement contributes the highest CO_{2e} emissions in terms of material production with 80.040 tonnes CO_{2e}. This is because of the long production process of cement, where each ton of cement production will produce emissions of 1ton CO_{2e} [15]. The results of the estimated CO₂ emissions are shown in the figure 4.

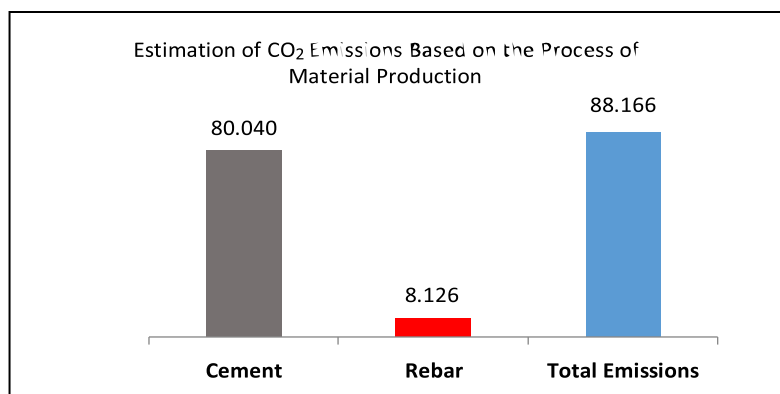


Fig. 4. CO_{2e} Emissions Based on the Material Production Process

4.1.2. Equivalent CO₂ emissions in material transportation

The calculation of CO_{2e} emissions from the transportation of rigid pavement materials can be seen in table 5. In this calculation, it is assumed that the vehicle used is new so that the fuel consumption of each vehicle is the same, and the speed of the vehicle is the same as the speed of the vehicle in an empty load state. The emissions generated by transportation of geotextile materials and joint sealants are considered minimal, and are not taken into account.

Table 5. The CO_{2e} Emissions Based on Transportation Material of Rigid Pavement

No	Material	Vol (ton)	Density (ton/m ³)	Vol (m ³)	Distance to Project site (km)	Number of Trips	Total Distance (km)	Fuel Consumption (litre)	CO ₂ e Emission (ton)
(1)	(2)	(3)	(4)	(5)= (3)/(4)	(6)	(7)= (5)/ capacityx2	(8)= (6)x (7)	(9)= (8)/ 3.5	(10)= (9)x2.66/ 1000
1	Cement	80.040	3.150	25.410	341	4	1364	389.714	1.037
2	Fly Ash	1.020	2.150	0.474	142	2	284	81.143	0.216
3	Coarse Aggregate	225.240	1.350	166.844	7	34	238	68	0.181

4	Fine Aggregate	217.680	1.400	155.486	41	32	1312	374.857	0.997
5	Rebar	3.386	7.850	0.431	485	2	970	277.143	0.737
Total									3.168

Note: The transportation vehicle is trailer truck for cement (capacity of 14.8 m³), and dump truck for other materials (capacity of 10 m³), fuel is diesel, fuel consumption is assumed 3.5 km/litre, emission of diesel = 2.66 kgCO₂/litre.

For the material transportation, cement contributes to the highest CO_{2e} emissions of 1.037 tonnes of CO_{2e}. This is because of the long distance of the source of material from Gresik City to the project location in Palur of 341 km. Moreover, as there is a large amount of material needed, causing a great number of transportation trips as well. The CO_{2e} emissions produced by the transportation of fine aggregate are almost as much as the CO_{2e} emissions from the cement transport. This is due to the large volume of material and the distance of the material source from Muntilan to Palur, Karanganyar which is 41 km a way, thus causing large amount of energy usage. The CO_{2e} emissions produced by other materials are presented in figure 5.

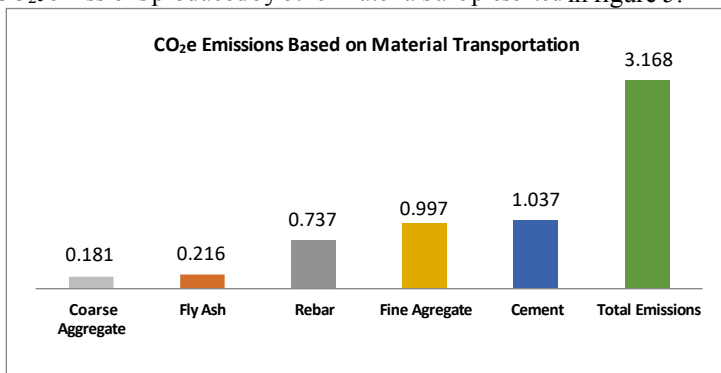


Fig. 5. The CO_{2e} Emissions Based on Material Transportation

4.2. On-site construction activities

The CO_{2e} emissions in the construction stage are produced by the heavy equipment used for the compaction and casting process. The emissions are estimated based on machine operating time, machine fuel consumption per hour, and conversion rates for the fuel used. The amount of CO_{2e} emissions during the rigid pavement construction can be seen in the table 6.

Table 6. The CO₂ emissions equivalent to the use of heavy equipment in the Rigid Pavement.

No	Work.	Vol. (m ³)	Heavy Equipment	Qty	Fuel Consumption (ltr/hr)	Coef of Equipment (hr/m ³)	Operating Hour (hr)	Fuel Consumption (ltr)	CO ₂ e Emission (ton)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)= (3)x(7)/(5)	(9)= (6)x(8)x(5)	(10)=(9)x2.66 / 1000	
1	Levelling Concrete t = 10cm	60	Batching Plant	1	31.5	0.024	1.429	45	0.120	
			Genset Nissan	1						
			Truck Mixer	3	20.85	0.061	1.217	76.119	0.202	
			Concrete Vibrator Generator	1	6.3	0.061	3.651	23.000	0.061	
2	Rigid Pavement t = 30 cm	180	Batching Plant	1	31.5	0.024	4.286	135.000	0.359	
			Generator	1						
			Truck Mixer	3	20.85	0.061	3.651	228.357	0.607	
			Concrete Vibrator Generator	1	6.3	0.061	10.952	69.000	0.184	
			Generator	1						
Concrete Cutter Generator	1	6.3	0.011	2.000	12.600	0.034				
Total									1.567	

Note : Emission of diesel = 2.66 kg CO₂/ ltr

Figure 6 shows the summary of the estimated CO₂ emissions heavy equipment used in this project. Estimated CO₂e emissions produced during concrete production come from generators that drive batching plants which are 0.479 tonnes of CO₂e. The size of the CO₂ emissions produced depends on the volume of concrete needed. After the concrete production process, the concrete is ready to be distributed to the project location, which will then be laid out. During the distribution process, the heavy equipment that contributed the most CO₂ emissions was the mixer truck which is 0.810 tonnes of CO₂e. This is because the demand for concrete is very high so that the operational time of the truck will also be large, which affects the amount of fuel used. The CO₂ emissions produced by heavy equipment during concrete production and the complete spreading is presented in the figure 6.

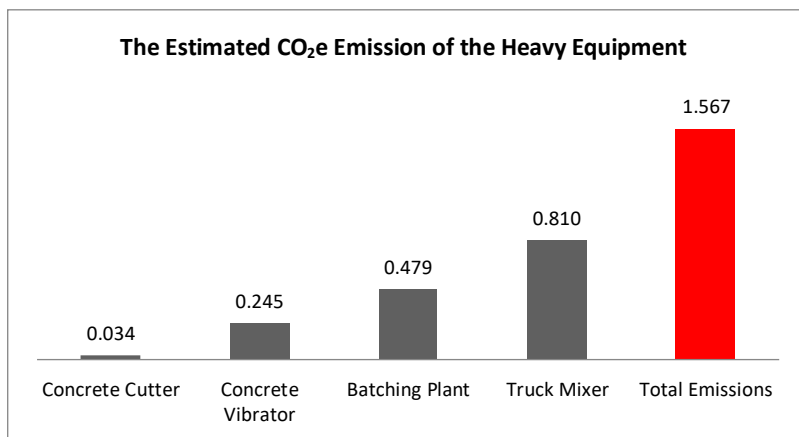


Fig. 6. The CO₂e Emission of the Heavy Equipment.

5 Discussion

Emissions generated during the production process, material transportation, and heavy equipment usage are based on the areas of the rigid pavement. The total CO₂e emissions from the construction of the rigid pavement under review is equal to 92.901 tonnes CO₂e.

Table 7 The CO₂ Emission on Rigid Pavement Construction Process

Type of Road Construction	CO ₂ Emission of off-site project (tonnes CO ₂) (A)		CO ₂ Emission of on-site project (tonnes CO ₂) (B)		Total (A)+(B)
	Material Production	Material Transport	Concrete Production	Spreading	
Rigid Pavement	88.166 (94.9 %)	3.168 (3.4 %)	0.479 (0.5 %)	1.088 (1.2 %)	92.901
	91.334 (98.3 %)		1.567 (1.7 %)		

Figure 7 shows a schematic diagram revealing the sources and the values of the CO_{2e} emissions of the rigid pavement under review.

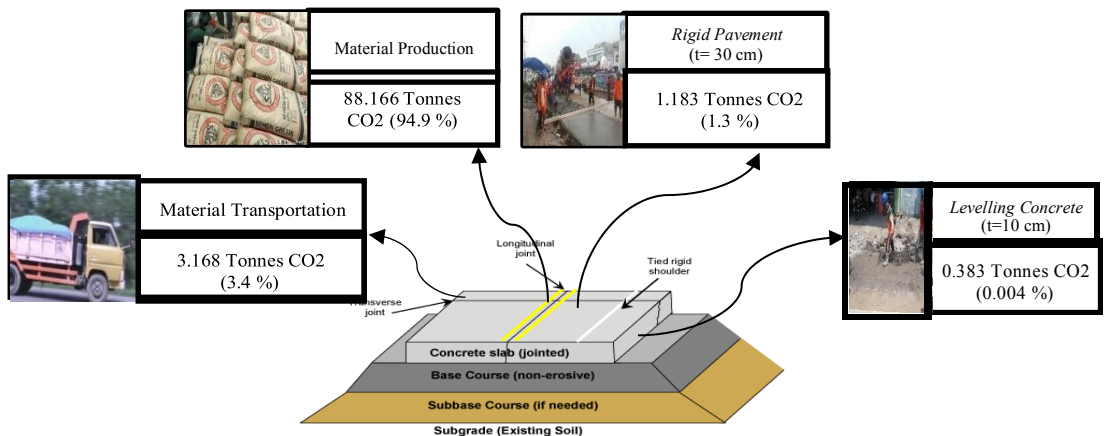


Fig. 7. Construction Process of Rigid Pavement

In this rigid pavement construction process, the largest CO_{2e} emissions are produced during the material production, which is 88.166 tonnes CO_{2e}, equivalent to 94.9% of the total CO_{2e} emissions. The production process of cement and rebar produces very high CO_{2e} emissions, because they are produced through a long process and require very high energy usage. Innovative efforts are needed to create new technologies that produce alternative materials that have material properties similar to cement, but with more durability and sustainability, so that the CO_{2e} emissions can be reduced.

Building structures engineering using green cement and wood materials will reduce carbon emissions significantly [17]. One alternative material that is more environmentally friendly is to use CO₂ Eco - Structure. CO₂ Eco-Structure is a casting method using CO₂ and silica sand. It consists of two types, i.e. yielding Type I and yielding Type II. Type I is made by injecting CO₂ into silica sand, so that it only has compressive strength. The aim is to be used for areas affected by surface subsidence. Type II is made of Type I which has impregnated with epoxy resin, creating a structure that has compressive strength equals to tensile strength [18].

The use of energy and the highest carbon producer occurs at the operational stage, this should be a concern for the structural engineers to be more innovative in producing designs [19]. Recycled materials for road pavement at the base and subbase layers can potentially reduce global warming by 20%, energy consumption by 16%, water consumption by 11%, and hazardous waste generation by 6% [20]. Similarly, research in Australia states that recycled material which is reused as a coating material has lower emission levels than new material [21]. By adopting the principle of environmentally friendly road planning using the concept of low-

impact procedures in producing materials and utilizing recycled materials, it will have great potential to reduce environmental impacts [22]

From the case study, it can be learned that the most CO₂ emissions are produced from the process of material production and transportation from the factory to the project site with an estimate of around 98%, while in the implementation of construction on site is only 1-2%. The high emission in the production process is due to the many stages to produce materials in the factory. This is in line with research which found that concrete, aluminium, and steel are among the materials with the highest energy and they are also responsible for a large amount of CO₂ emissions [23]. For this reason, innovation and efficiency during the production period are needed in creating green construction, particularly green road of rigid pavement.

6. Conclusion

This research was carried out on the rigid pavement of Palur Flyover project, sections STA 0 + 350 to 0 + 450 by observing the construction process, including the process of material production, material transportation, and the on-site activities, resulting in a total of 92.901 tonnes CO_{2e}. From this figure, the CO₂ emissions from the off-site project activities were 91.334 tonnes CO_{2e} (equals 98.3% of the total CO₂ emissions), which were obtained from the material production process of 88.166 tonnes CO_{2e} (94.9%) and the material transportation process of 3.168 tonnes CO_{2e} (3.4%). While the CO₂ emissions from on-site activities was equal to 1.567 tonnes CO_{2e} (1.7%), which were obtained from the concrete production process of 0.479 tonnes CO_{2e} (0.5%), and spreading concrete of 1.088 tonnes CO_{2e} (1.8%). From this case, it can be inferred that the biggest emissions are generated from the off-site project activities.

The production process of cement and rebar produces very high CO_{2e} emissions. Cement has the biggest CO_{2e} emission during the material production process of 80.040 tonnes CO_{2e} and steel rebars of 8.126 tonnes CO_{2e}. This study shows that the highest CO₂ emissions are from the process of material production and transportation from the factory to the project site with an estimated range of 98%, while in the construction on site only 1-2%. Further research can be done by comparing the estimated CO₂ emissions for other types of infrastructure projects, such as bridges, drainage, dams, etc.

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