Carbon Footprint Calculator for Malaysia Green Highway Index

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ABSTRACT
The large-scale transportation infrastructure construction in developing countries such as Malaysia requires emission estimation method for better calculation. The aim of this paper is to estimate the carbon footprint emission in the unit of ton of carbon dioxide equivalents (t CO_2e/km-lane). This study proposed a life cycle assessment method to estimate the carbon footprint (CO_2e) emission based on bridge work under construction in expressway of Malaysia. The results show that highest carbon footprint is from construction of pier column 5.3864 t CO_2e/pier column. Because due to highest volume of structural with 12 m depth and 1500 mm cylinder size. The result followed by construction of pile, crosshead, pile cap, beam launching, parapet wall and slab deck at 3.5396, 3.5124, 2.6354, 0.1975, 0.0648, 0.0236 t CO_2e/unit respectively. In the sources, emission from on-site construction machinery produce the highest carbon footprint 2.7566 t CO_2e/unit, followed by emission production of raw material and transportation of material, 0.3309 and 0.0778 CO_2e/pier column respectively. The result in this study can be considered as references for carbon footprint calculator to calculate emission in other expressway of Malaysia.

CCS Concepts
• **Hardware→ Impact on the environment**

Keywords
"Emission consumption"; "Carbon footprint"; "Bridge Construction"; "Highway"

1. INTRODUCTION
As Malaysia transforms into a high-income nation, the national development strategy must be in line with the megatrends of the world, especially climate change. The Malaysian Highway Authority (MHA) committed to contributing the government's target to cut national carbon emission intensity by 45 percent by 2030 based on 2005 emission levels. The demand for environment conservation requires the construction industry to emphasis more on sustainable application as an important element to move towards green practices. Different methods to reduce the emissions of pollutants have be proposed in various countries such as used eco tax and carbon tax to promote activities with low environmental impacts. The purpose of this paper is to estimate the carbon footprint emission in the unit of ton of carbon dioxide equivalents (t CO_2e/unit). Additionally, a selection on few first highways will be evaluated for the Carbon Footprint Assessment tool and will be used as a baseline study for Malaysia Highway Authority towards setting their target for carbon emission reduction in the upcoming years. Lastly, with this tool it will provide an outlook on the trends of the greenhouse gases emissions that can be utilized to come out with a better strategy to manage green highway in Malaysia.

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2. LITERATURE REVIEW
2.1 Greenhouse Gases
There are six main greenhouse gases which cause climate change and are limited by the Kyoto Protocol; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). Each gas has a different global warming potential (Kyoto Protocol, 2018).

2.2 Carbon Dioxide Equivalent
Carbon footprint is the total amount of greenhouse gases impacting the environment produced both directly and indirectly due to various human activities by an individual, event, organization, and product, expressed in equivalent tons of carbon dioxide (t CO_2e).

- The direct energy = the energy purchased by contractor's onsite and off-site to facilitate any construction, prefabrication, administration and transport activities under their control (including sub-contractors).
- The indirect energy = the energy embodied in materials used.

Figure 1 show all the CO_2 gas emitted from machinery is converted into CO_2e by multiplying the weight of the CO_2 being measured by its respective Global Warming Potential (GWP). The GWP value for CO_2 is 1.

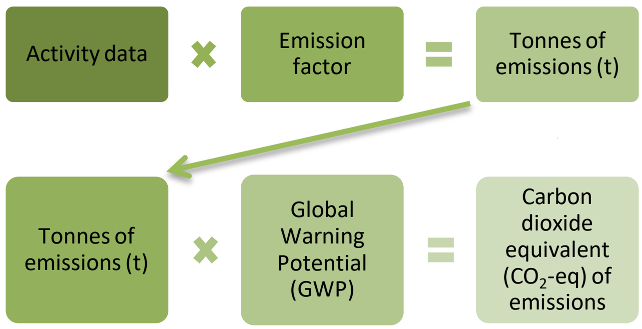

Figure 1. Formula converted all GHG to a CO_2 equivalent (Sreedhar et al., 2016).

2.3 Sources of Carbon Footprint Emission

According to Kean et al,. (2016), sources of carbon footprint emission during construction activities is due to the use of diesel engines in on and off-road construction machinery. Carbon emissions from the construction industry result from fuel consumed by on and off-road construction machinery and from electricity consumed to provide power to construction tools and offices (U.S. Environmental Protection Agency, 2008). Due to large number of using on the off-highway machine such as bulldozer, scraper, excavator and dump truck; for varies construction work, total activity and emissions from these sources are uncertain. The embodied emissions is the GHG emissions which the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself.

2.4 Emission Factors

Table 1 shows the Greenhouse Gases (GHG) emissions factor for transportation of materials. Based on the study, transport from the production plant to the building site, a 20-28 ton truck covering an average distance of 100 km has been considered. Moreover, other emission factor of CO_2 emission is show in Table 2 base on review of previous studies.

Table 1. GHG emissions factor for transportation materials (Li et al., 2010)

Method of transportation	Energy use (MJ/ton km)	Fuel type	Fuel CO_2 emission factor (g CO_2e/MJ)	GHG emission factor (kg CO_2e/ton km)
Truck	2.275	Diesel	70.0	0.159

3. METHODOLOGY

This study attempts to propose a Life Cycle Assessment (LCA) method to estimate CO_2e emission. The data was being collected which record the detail consumptions of materials and energy. In the study scope, the sources of emission divided into three stage: raw material production, material transportation and onsite construction. The total emissions are the sum of each stage:

$$Q = Q_1 + Q_2 + Q_3 \qquad (1)$$

Where, Q is the total amount of CO_2 emission from highway construction; Q_1, Q_2, and Q_3 is the amount of CO_2 emission from raw material production, material transportation and onsite construction, respectively. The unit of Q, Q_1, Q_2, and Q_3 is t CO_2e/km-lane.

Table 2. Emission factor

Sources	Emission Factor	Unit	Reference
Concrete	0.0065	kg CO_2/kg	(White et al., 2010)
Water	0.3796	kgCO_2/m^3	(SAJ, 2014)
Steel	2.6553	kg CO_2/kg	(Chen et al., 2017)
Aggregate	0.0026	kg CO_2/kg	(Moa et al., 2017)
Sand	0.0025	kgCO_2/m^3	(Moa et al., 2017)
Paper	1.3901	t CO_2/t	(Wang et al., 2015)
Diesel	2.6800	kg CO_2/l	(Wang et al., 2015)
Petrol	2.3000	kg CO_2/l	(Wang et al., 2015)
Lorry	0.2821	kgCO_2/km	(Sreedhar et al., 2016)
Bulldozer	0.1663	kgCO_2/km	(Sreedhar et al., 2016)
Grader	0.539	kgCO_2/m^3	(Sreedhar et al., 2016)
Backhoe	0.1772	kgCO_2/ton	(Sreedhar et al., 2016)
Excavator	0.1772	kgCO_2/km	(Sreedhar et al., 2016)
Dump track	0.2821	kgCO_2/ton	(Sreedhar et al., 2016)
Compactor	0.102	kgCO_2/ton	(Sreedhar et al., 2016)
Tanker	0.376	kgCO_2/m^3	(Sreedhar et al., 2016)

According to Kean et al,. (2016), sources of carbon footprint emission during construction activities is due to the use of diesel engines in on and off-road construction machinery. The possible sources of carbon footprint throughout the entire life cycle of highway maintenance show in Table 3 below. Embodied emissions also should consider in term life cycle assessment. The embodied emissions is the GHG emissions which the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself.

Table 3. Sources of carbon footprint throughout the entire life cycle of highway construction

Onsite construction	Embodies carbon	
	Material transportation	Raw material production
Lorry	Ready mix	Concrete
Drilling machine	Lorry	
Crawler crane	Dump truck	
Excavator		
Backhoe loader		
Skylift		
Mobile crane		

In order to develop the sources, the criteria that had been carried from literature review and questionnaires were used. The questionnaires were distributed to the respondents amongst qualified professionals followed by expert reviews by interviews for validation of output. The collected data ware rearrange and analysis in order to determine its correlation between different stage and activity. Through this method, the fuel consumption can be predicted accuracy. After the baseline has been set, the carbon footprint consumption reduction will be target and the target can be set.

4. FINDINGS

The major aim of this study was to establish a carbon footprint estimation tool that incorporates various GHG emissions that are eminent during any bridge construction project. A typical bridge construction project involves.

- Piling
- Pilecap
- Pier column
- Crosshead
- Beam launching
- Slab deck
- Parapet wall

Once the various parameters to be considered in this study were identified, the various energy sources and the various emissions for these processes were studied for their relative damage to the environment considering their GWP's.

Using the generic emission factor method, a spreadsheet computer tool using the Microsoft® Excel platform was developed designated "Carbon Footprint Calculator for Malaysia Green Highway Index" with various modules that correspond to different stages of the highway construction project to estimate the total t CO_2e for any highway activity. The total t CO_2e per unit activity estimated for bridge work as shown in Table 4-10 below.

Table 4. Pile (Bored pile)

Machineries	nos	Fuel (l/day) for 1 nos	Productivity
Drilling Rig	4	70	3 pile/day
Crawler Crane	4	70	
Excavator	2	70	

Embodies carbon	Amount	unit
In construction materials	191.93	m^3 / day
Transport material	353	km / day
In fuels used	700	liter / day

Table 5. Pilecap

Machineries	nos	Fuel (l/day) for 1 nos	Productivity
Backhoe	2	50	1 pilecap/day
Excavator	1	70	
Vibrator Sheet Pile	1	70	

Embodies carbon	Amount	unit
In construction materials	25	m^3 / day
Transport material	66.67	km / day
In fuels used	240	liter / day

Table 6. Pier columns

Machineries	nos	Fuel (l/day) for 1 nos	Productivity
Backhoe	1	50	3 pile/day
Skylift	1	30	
Crawler Crane	2	70	
Mobile Crane	2	70	

Embodies carbon	Amount	unit
In construction materials	21.21	m^3 / day
Transport material	70.7	km / day
In fuels used	360	liter / day

Table 7. Crosshead

Machineries	Nos	Fuel (l/day) for 1 nos	Productivity
Mobile Crane	2	70	1 crosshead/day
Skylift	2	30	

Embodies carbon	Amount	unit
In construction materials	75	m^3 / day
Transport material	250	km / day
In fuels used	200	liter / day

Table 8. Beam launching

Machineries	nos	Fuel (l/day) for 1 nos	Productivity
Mobile Crane	1	80	8 beam/day
Skylift	1	30	

Embodies carbon	Amount	unit
In construction materials	23	m^3 / day
Transport material	76.67	km / day
In fuels used	110	liter / day

Table 9. Slab deck

Machineries	Nos	Fuel (l/day) for 1 nos	Productivity
Mobile Crane	2	80	115 m^2/day
Skylift	2	30	

Embodies carbon	Amount	unit
In construction materials	23	m^3 / day
Transport material	76.67	km / day
In fuels used	220	liter / day

Table 10. Parapet wall

Machineries	Nos	Fuel (l/day) for 1 nos	Productivity
Mobile Crane	2	80	30 m/day

Embodies carbon	Amount	unit
In construction materials	15	m^3 / day
Transport material	50	km / day
In fuels used	160	liter / day

4.1 Summary Total Emission of Bridge Work

Table 11 provides a summary of the various activity used for the development of the model to estimate the t CO_2e produced by the facility from very reliable sources. As presented, the results show that highest carbon footprint is from construction of pier column 5.3864 t CO_2e/pier column. Because due to highest volume of structural with 12 m depth and 1500 mm cylinder size. The result followed by construction of pile, crosshead, pile cap, beam launching, parapet wall and slab deck at 3.5396, 3.5124, 2.6354, 0.1975, 0.0648, 0.0236 t CO_2e/unit respectively. In the sources, emission from on-site construction machinery produce the highest carbon footprint 2.7566 t CO_2e/unit, followed by emission production of raw material and transportation of material, 0.3309 and 0.0778 CO_2e/pier column respectively.

Table 11. Summary of result

Activity	Total CO_2 (MT CO_2-eq) per activity		
	Scope 1	Scope 3	All scope
A. Bored pile	1.7867	1.7530	3.5396
B. Pilecap	1.8377	0.7976	2.6354
C. Pier Column	2.7566	2.6299	5.3864
D. Crosshead	1.5314	1.9810	3.5124
E. Beam Launching	0.1053	0.0922	0.1975
F. Slab Deck (area)	0.0146	0.0090	0.0236
G. Parapet wall (m)	0.0108	0.0239	0.0648

5. CONCLUSION

The main objective of this study was to develop a toolkit called "Carbon Footprints Calculator for Malaysia Green Highway Index" to quantify the carbon footprints of the different construction activity used in bridge construction. The Carbon Footprints Calculator housed the various highway construction stages, including: material production and transportation, and specifically, on-site combustion from construction machinery to estimate the total t CO_2e.

In this study, based on the collected data from 7 different activities in construction of bridge, this paper proposed the general CO_2 emission factor for construction of bridge. The estimated emission factor of construction of pier column, pile, crosshead, pile cap, beam launching, parapet wall and slab deck at 5.3864, 3.5396, 3.5124, 2.6354, 0.1975, 0.0648, 0.0236 t CO_2e/unit respectively.

The results in this study may benefit the highway maintenance in Malaysia, especially in the mill and pave work. In the future, a supplementary index may be added for overall assessment of projects. In addition, the detailed guidance for construction operations (e.g. equipment selection, green construction techniques) may also be considered in future.

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