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Carbon footprints calculator of highway pavement rehabilitation: The quantification of carbon emissions per unit activity

Che Muhammad Fatihi Hafifi Che Wahid¹, Eeydzah Aminudin¹, Muhd Zaimi Abd Majid¹, Mohd Rosli Hainin¹, Mohd Khairul Idham Mohd Satar¹, Muhammad Naquiuddin Mohd Warid¹, Rozana Zakaria¹, Muhammad Rozaid Ramli¹, Rosli Mohamad Zin¹, Zainura Zainon Noor¹, Ain Naadia Mazlan¹, Omar Sedeeq Yousif¹, Monh Neardey¹, Azman Mohd Jais², Rohaya Abdullah², Yazlin Salfiza Mohd Yazid¹ and Nadzrol Fadzilah Ahmad²

¹ School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

² Lembaga Lebuhraya Malaysia, Wisma Lebuhraya, KM-6, Jalan Serdang - Kajang, 43000, Malaysia

E-mail: eeydzah@utm.my

Abstract. Carbon dioxide that emitted throughout the construction lifespan is crucial from development of design, construction, up to demolition stage. Focusing in the rehabilitation of highway pavement, the activities that normally involved are from milling, roller up to dumping the wastes asphalts. The aim of this paper is to estimate the carbon footprint emission in unit of tonnes for carbon dioxide equivalents (t CO₂-eq/km-lane). The case study involved based on five selected projects for north-south bound expressway of Malaysia. The results show that highest carbon footprint were from the Mill and Pave 250 mm (MP 250) with 117.94 t CO₂-eq/km-lane. This is due to its depth of pavement with 140 mm dense bituminous macadam, 60 mm asphalt concrete base course and 50 mm asphalt concrete wearing course as compared as other Mill and Pave. The result followed by MP 200, MP 110 and MP 50 at 95.19, 54.10, and 27.37 t CO₂-eq/km-lane respectively. The critical activities involved during the construction shows the asphalt concrete production as the highest generation of emission with 53.78 t CO₂-eq/km-lane, followed by lorry transportation of asphalt waste, lorry transportation of asphalt concrete, fuel consumption from machineries, neomed coat, and water consumption with the value of 28.58, 24.50, 10.83, 0.23, and 0.01 t CO₂-eq/km-lane respectively. The results from this study considered as references guidelines for carbon footprint calculator to calculate emission as compared to other expressway in Malaysia.

1. Introduction

As Malaysia transforms into a high-income generation, there is a need for national development strategy in line with current megatrends of the world focusing in climate change issues. One of main agenda of Malaysia's involvement was pledging in cutting down the national carbon emission intensity to 45 per cent by 2030 based on 2005 emission levels. As since June 2017, 150 countries have ratified the Paris Climate Agreement regarding this issue. Align with pledging, the country



initiatives were extended to the development of The National Green Technology Policy of greenhouse gases emission in order to ensure sustainable development approach can significantly progress besides providing the major improvement, especially in construction sector.

Different methods to reduce the emissions of pollutants in various countries proposed such as used eco tax and carbon tax in promoting the activities involved in line with low environmental impacts. These emission reduction methods require accurate measurement [1]. Therefore, this study focuses on the development of Carbon Footprint Calculator tool for highway construction in Malaysia, which will create tools that allow every sector (contractor, concessionaire and authority) to calculate, monitor and receive feedback on their personal emissions. In addition, these carbon footprint calculators are not focuses on the amount of emissions generated but also providing detail activities related to construction such as list of machinery and quantity of material needed in each activity.

Carbon footprint technology is still evolving, especially with regard to the accuracy of estimations and transparency of calculations methods, as a means of benchmarking and comparison. Hence, there is a need to explore, in more detail, the consequences of personal choices before setting a normative concept of responsible behaviour toward emissions reductions [2].

The purpose of this research is to estimate the carbon footprint emission in the unit of tonnes of carbon dioxide equivalents (t CO₂-eq/km-lane) based on the activities involved during the construction of rehabilitation of pavement. 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 highway organization in planning the setting target for carbon emission reduction for upcoming years. Lastly, with this tool it will provide an outlook on the trends of the GHG emissions that can be utilized to come out with a better strategy to manage green highway in Malaysia.

2. Research methodology

This study attempts to propose a Life Cycle Assessment (LCA) method to estimate CO₂-eq 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 stages: raw material production, material transportation and onsite construction. The total emissions are the sum of each stage:

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

Where, Q is the total amount of CO₂ emission from highway construction; Q₁, Q₂, and Q₃ is the amount of CO₂ emission from raw material production, material transportation and onsite construction, respectively. The unit of Q, Q₁, Q₂, and Q₃ is t CO₂-eq/km-lane.

Table 1. Sources of carbon footprint throughout the entire life cycle of highway maintenance.

Onsite construction	Embodies carbon	
	Material transportation	Raw material production
Milling machine	Lorry	Asphalt concrete
Paver	Truck	DBM40
Tandem Roller	Van	ACBC28
Tyre Roller		ACWC20
Bobcat		Tack coat
Lorry		Prime coat
Gen Set		
Compressor		
Water tanker lorry		
Diamond cutter		

The sources of emission produce during construction activities normally is the usage of diesel engines in on and off-road construction machinery [3]. The possible sources of carbon footprint throughout the entire life cycle of highway maintenance show in Table 1 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.

3. Data collection

This study focuses on the machineries and materials used in rehabilitation phases that cover input and output in terms of quantities of materials and fossil fuel consumption for machineries. The pavement rehabilitation type in this study is Mill and Pave 250mm (MP 250), Mill and Pave 200mm (MP 200), Mill and Pave 110mm (MP 110), and Mill and Pave 50mm (MP 50) as show in Table 2. Table 3 show the average route length, quantities of material asphalt such as dense bitumen macadam (DBM40), asphaltic concrete binder course (ACBC28), and asphaltic concrete wearing course (ACWC20), neomed coat and quantity of water in difference type of pavement rehabilitation in one day's construction were obtained from the respective project officers via interviews. Table 4 summarizes the quantity of fuel consumption from machineries for one day construction. The types of lorry used at the site and the fuel used of the lorry are shown in Table 5.

Table 2. Type of pavement rehabilitation in mill and pave work.

Type	Description
MP 250	Removal of the asphalt layer and base material to a depth of 250mm and replacement with 140mm DBM40, 60mm ACBC28 and 50mm ACWC20
MP 200	Removal of the asphalt layer and base material to a depth of 200mm and replacement with 90mm DBM40, 60mm ACBC28 and 50mm ACWC20
MP 110	Removal of the asphalt layer to a depth of 110mm and replacement with 60mm ACBC28 and 50mm ACWC20
MP 50	Removal of the asphalt layer to a depth of 50mm and replacement with 50mm ACWC20

Table 3. The data obtained from the respective site engineer via interviews^a.

Type	Average length (meter/day)	Asphalt (tonne/day)	Neomed coat (kg/day)	Water (litre/day)
MP 50	330	155	600	3000
MP 110	260	258	200	3000
MP 200	176	313	200	3000
MP 250	140	310	200	3000

^a The width of one lane is 4.1 meter.

Table 4. The quantity of fuel consumption from machineries for one day construction.

Machineries	Average fuel usage (litre/day)					
	Sub con	Sub con	Sub con	Sub con	Sub con	Average
	A	B	C	D	E	
Milling machine	100	200	100	200	200	160
Paver	30	50	50	60	60	50
Tandem Roller	10	50	30	20	20	26
Tyre Roller	10	50	30	20	20	26
Bobcat	10	50	20	30	30	28
Lorry (sprayer)	80	80	50	50	50	62
Generator set	5	10	5	5	5	6
Lorry (compressor)	80	80	50	50	50	62
Compressor	10	10	10	10	10	10
Lorry (water tanker)	80	80	80	50	50	68
Diamond cutter	3	3	3	3	3	3
Van	30	33	25	30	30	30

Table 5. The types and the fuel used of the lorry for transport the material^b.

Transportation	Average distance per one trip (km/trip)	Average fuel usage for one trip (litre/trip)
Lorry transport the asphalt from plant	60	100
*tyre 10 : 21-26 ton/trip		
*tyre 12 : 27-36 ton/trip		
Lorry transport the asphalt waste	60	100
*tyre 10 : 9.5 m3/trip		
*tyre 12 : 16 m3/trip		

^b The fuel used in the processes was brought by lorry trucks from the supply source, which is 60 km away. This detail is regarded as the fuel transportation inventory value.

4. Data analysis

For normal average consumption of energy per unit time and the equipment running time for a particular unit process can be obtained by multiplying the average energy consumption per unit of time by the running time of equipment, the fuel consumption by the equipment can be obtained [4]. Then, the total consumption can be determined by summing the consumption of all equipment used in the same unit process.

The normal emission factors estimates for water is 0.376 kg CO₂/m³ [5], asphalt concrete 0.0238 kg CO₂/kg [6] [7] [8], emulsified bitumen neomed 0.16 kg CO₂/kg [9] and diesel 3.164 kg CO₂/kg [9] [10] [11]. It can be calculate by multiplying the activity data with emission factor. Normally the CO₂ gas emitted from machinery is converted into CO₂-eq by multiplying the weight of the CO₂ being measured by its respective Global Warming Potential (GWP) [4]. The GWP value for CO₂ is quantified as one. As for the machineries involved during construction, the amount of fuel were identify based on consumption of fuel taken into account to correspondent the amount of CO₂ emissions. The total emission and energy factors are presented based on calculated per kilometre. Figure 1 shows the calculation on calculate the energy consumption of machineries.

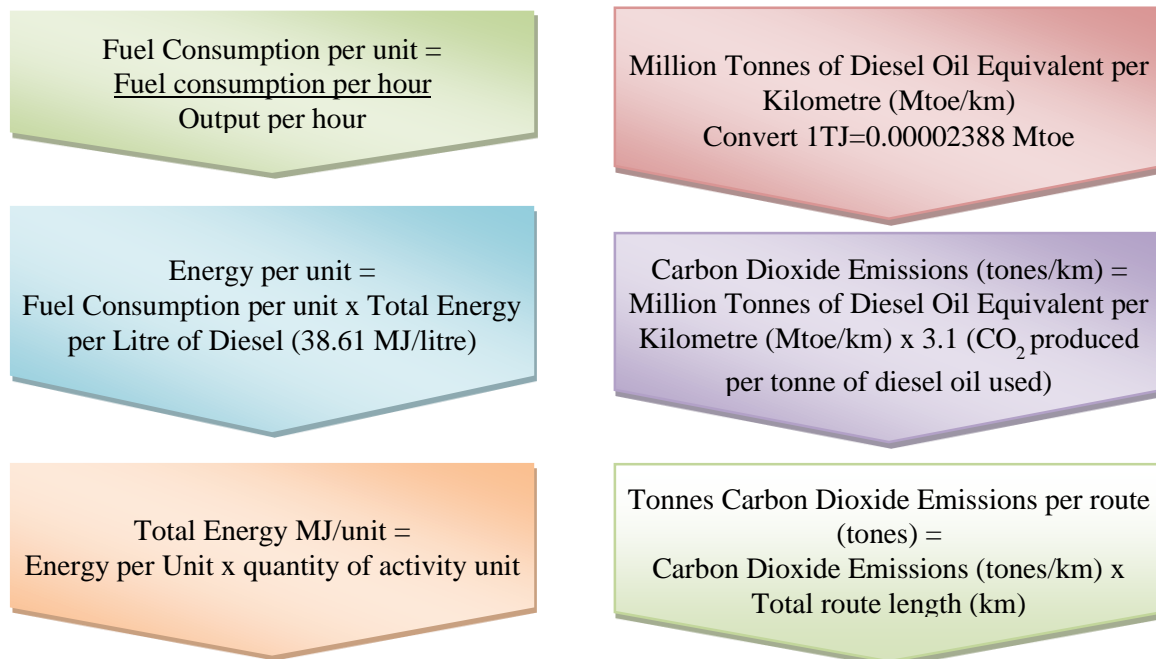


Figure 1. Justify the caption. Calculation of energy consumption.

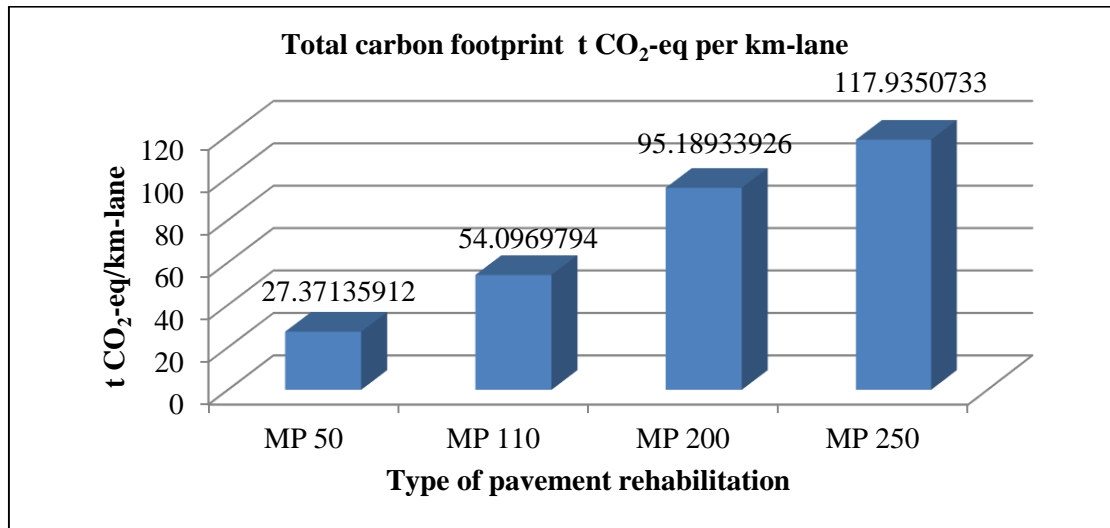
Figure 2. Calculation of carbon dioxide from diesel used.

Diesel fuel has a Lower Calorific Value (LCV) of 35.1 MJ/litre where the energy contained within the fuel. It has a Precombustion Value (10%) of 3.51 MJ/litre when it takes a total of 10% of the diesel energy to get the diesel from the earth to usable form. Therefore the 'Total Energy per Litre of Diesel is 38.61 MJ/litre' where it includes a precombustion value of 10% [12]. The amount of 38.61 MJ/litre will be an assumption if all the machines used the diesel as the fuel. Moreover, figure 2 shows how the calculation will be used to calculate the CO₂ emission of machineries. From the total Energy, 'Total Energy per Kilometre (TJ/km)' the value will be convert into the 'Million Tonnes of Diesel Oil Equivalent per Kilometre' by the conversion factor turning TJ into Mtoe (1 TJ = 0.00002388 Mtoe). The next will be identify as 'Carbon Dioxide Emissions (tones/km)'. This can be measure by multiplying the 'Million Tonnes of Diesel Oil Equivalent per Kilometre (Mtoe/km)' by 3.1. Standard of Environment Impact Assessment shows that there are 3.1 tonnes of carbon dioxide has been produced by per tonne of diesel oil used [13]. Then, the amount of carbon emission per route can be obtained with this calculation.

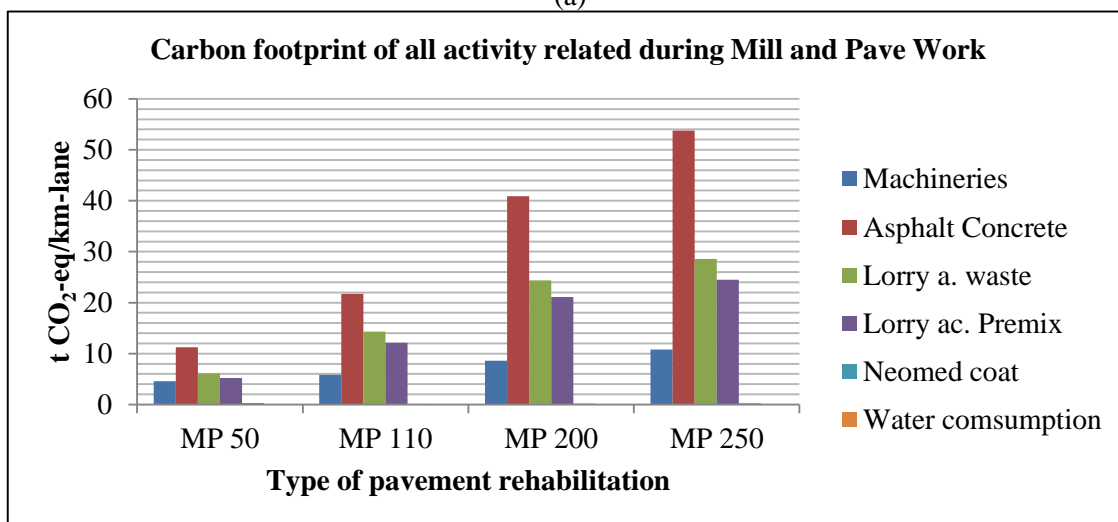
5. Result and Discussion

The carbon footprints of machineries in road pavement rehabilitation originates from different types of machineries used on the different layers, such as milling work, the DBM layer, the ACBC layer, and the ACWC layer. The produced carbon footprint is associated with embodies carbon and transportation values. Figure 3(b) shows the total carbon footprint emitted from pavement rehabilitation. The highest carbon footprint in pavement rehabilitation work is from Mill and Pave 250mm (MP 250) a total of 117.94 t CO₂-eq/km-lane. Because due to its highest depth of pavement with 140 mm dense bituminous macadam, 60 mm asphalt concrete base course and 50 mm asphalt concrete wearing course, followed by MP 200, MP 110 and MP 50 at 95.19, 54.10, 27.37 t CO₂-eq/km-lane, respectively. In the difference activity, asphalt pavement material produce the highest carbon footprint 53.78 t CO₂-eq/km-lane, followed by lorry transportation of asphalt waste from site construction to site disposal, lorry transportation of asphalt concrete from plant to site construction, fuel from machineries, neomed coat, and water consumption emit 28.58, 24.50, 10.83, 0.23, and 0.01 t CO₂-eq/km-lane respectively. The total result for the carbon footprint emission through all activity is

shown in figure 3(a). Figure 3(b) show the water consumption and neomed coat has the lowest carbon footprint emission, because its use is lowest among all materials.



(a)



(b)

Figure 3. Carbon footprint emission of the pavement rehabilitation: (a) Total activity, and (b) Separated

6. Conclusions

Overall, the major sources of CO₂ emission generated for Malaysian highway came from material production, followed by onsite construction, and transportation stage. The estimated emission factor of MP 250, MP 200, MP 100, and MP 50 is 117.94 t CO₂-eq/km-lane, 95.19 t CO₂-eq/km-lane, 54.10 t CO₂-eq/km-lane, and 27.37 t CO₂-eq/km-lane, respectively. This indicates that a proper invention on the technology for future is needed in producing the highway is necessary especially in the mill and pave work in order to cut down the emission produces from it sources.

7. References

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