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Review on the method for carbon footprint calculation of highway development

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Abstract. Highway infrastructure emits large quantities of carbon dioxide over their entire life cycle including emission from production of raw materials and also emission from construction, operation, maintenance, and rehabilitation of the roads. The past emission trends of carbon dioxide from these sectors are investigated through their sources while mitigation and abatement strategies are suggested. This paper brings together, for the first time, a systematic review of the carbon footprint calculator of 21 case study highway from 8 different countries were investigated. This review focuses on method for calculate carbon footprint of highway development, through the synthesis of the overall outcomes of these studies, to identify whether using excel tool or Life Cycle Assessment (LCA) software achieve better performance and easier to calculate the emission from highway development. It is observed that using excel tool is better to calculate and analysis the carbon footprint from many sources and stage compare than calculate using LCA software. Therefore, understanding the relationships between methods for calculate carbon footprint life cycle energy consumption and GHG emissions are critically important for highway agencies to evaluate their annual greenhouse gas emission reports.

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. Therefore, Malaysia has already signatory and pledged to cut national carbon emission intensity by 45 % by 2030 based on 2005 emission levels. Align with The National Green Technology Policy greenhouse gases emission was introduced in order to ensure sustainable development approach can significantly progress besides providing the major improvement, especially in construction sector.

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 [1].

Therefore, this study focuses on the comparison of carbon emission calculations by either using excel or software. An overview of the case studies from previous research is presented in Table 1. Some attributes such as country, date, type of LCA approach used and stage duration of scale analysis of previous research. The most common scale of analysis is production and construction process. The most common LCA method is studies focusing on create excel calculator tool are also frequent.

Table 1. Carbon Footprint quantification studies on road project.

Authors	Country	LCA Method		Scale of analysis				
		Crete Excel	Use LCA software	*P	*D	*C	*O	*M
Venmathy et al., 2015 [2]	Malaysia	/			/	/	/	/
White et al., 2010 [3]	U.S	/		/		/		
Santero et al., 2011 [4]	U.S	-	-	/		/	/	/
Kucukvar & Tatari, 2012 [5]	U.S		/*P-LCA	/		/		
Loijos et al., 2013 [6]	U.S		/*Gabi	/		/	/	/
Barandica et al., 2013 [7]	Spain	/				/	/	/
Wang, 2016 [8]	China	/		/		/		
Sreedhar et al., 2016 [9]	India	/		/	/	/	/	
Kamyab et al., 2015 [10]	Malaysia	/				/		
Thives & Ghisi, 2017 [11]	Brazil	/		/		/	/	/
Ghazy, et al., 2016 [12]	Egypt.		/*LCA-	/		/	/	/
Rahman, et al., 2017 [13]	Saudi A.	/	based			/	/	

*P-Production, *D-Design, *C-Construction, *O-Operation, *M-Maintenance

2. Carbon footprint calculation

Before undertaking the study in Malaysia, understanding of the definition of carbon footprint and the way calculations are made is to be understood first. According to Ramachandra, carbon footprint is the total amount of GHG emission caused direct and indirect by an individual, event, organization, and product, expressed in equivalent tons of carbon dioxide (t CO₂e) [14].

Embodied Emissions is 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. Carbon footprint consists of its initial embodied energy, its recurrent embodied energy and its operational energy over its lifetime. So, in order estimate the carbon footprints of a product, it is crucial to take into consideration the embodied energy of the product and also the transportation factor. With this, the total amount of carbon footprints caused by the product over the life stage can be estimated.

2.1. Scope

First step is essential to understand all possible sources of direct and indirect CO₂ emissions during the full life cycle period. There are many researchers quantifying the sources of carbon emission by divided into three scopes according to the GHG Protocol models [15]. Direct emissions Scope 1 are released from sources within the organizational boundaries of the entity being inventoried. Besides that, indirect emissions are consider in Scope 2 are released from sources outside of the organizational boundaries of the entity being inventoried but are a consequence of the energy purchases of the entity. Lastly, optional indirect emissions Scope 3 are a broad category that covers all other releases that are an indirect consequence of the entity's operations.

However, the ability of highway utilities to effect significant emission reductions or sequestration of GHGs may require the inclusion of projects impacting Scope 3 and Embodied Energy Emissions or other projects outside of their own boundaries. Scope 3 is direct emission, 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. For example, possible sources GHG emitters on highway development are discussed in table 2 - 4 below.

Table 2. Sources in scope 1 during full life cycle period of highway.

Sources	Design Stage	Construction Stage	Operation & Maintenance Stage
Fleet Vehicle	/	/	/
On-site construction by machine used		/	/

Table 3. Sources in scope 2 during full life cycle period of highway.

Sources	Design Stage	Construction Stage	Operation & Maintenance Stage
Electricity (power plant that generates the electricity consumed by the entity)	/	/	/

Table 4. Sources in scope 3 during full life cycle period of highway.

Sources	Design Stage	Construction Stage	Operation & Maintenance Stage
Material	/	/	/
Staff Commuting	/	/	/
Water	/	/	/
Waste	/	/	/
Transportation Supplier	/	/	/

2.2. Emission factors of emission sources

Carbon Footprint can be measured by estimating the amount emission emitted by multiplying activity data (such as the amount of fuel used) with relevant emissions conversion factors. Emission factors will be identified according to the data availability and cited based on the reference as show in Table 5 - 9 below.

Table 5. Emission factor for utilities.

Activity	Emission Factor	Unit	Sources
Electricity (Peninsular)	0.000694	t CO ₂ /kWh	SEDA, [16]
Electricity (Sabah & Wilayah Persekutuan Labuan)	0.000536	t CO ₂ /kWh	SEDA, [16]
Water	0.000376	t CO ₂ /m ³	Shimizu et al., [17]
Diesel	0.002672	t CO ₂ /liter	Defra, [18]
	0.003176	t CO ₂ /liter	Zainab et al., [19]
	0.002564	t CO ₂ /liter	Venmathy, [2]
	0.000185	t CO ₂ /km	Venmathy, [2]
Petrol	0.002322	t CO ₂ /liter	Defra, [18]
	0.002233	t CO ₂ /liter	Venmathy, [2]
	0.000201	t CO ₂ /km	Venmathy, [2]

Table 6. Emission factor for vehicle.

Activity	Emission Factor	Unit	Sources
Motorcycle	0.000107	t CO ₂ /km	Defra, [18]
Car	0.000216	t CO ₂ /km	Defra, [18]
Hybrid Car	0.000120	t CO ₂ /km	Defra, [18]
4WD	0.000183	t CO ₂ /km	Defra, [18]

Table 7. Emission factor for transportation of material.

Activity	Emission Factor	Unit	Sources
Dump Truck	0.001100	t CO ₂ /km	Sreedhar et al., [9]
Truck (14 ton)	0.001100	t CO ₂ /km	Sreedhar et al., [9]
Truck standard 16-24 tons	0.000282	t CO ₂ /ton-km	White et al., [3]
Lorry	0.000846	t CO ₂ /km	White et al., [3]
LMV (Goods)	0.000914	t CO ₂ /km	Sreedhar et al., [9]
LMV (Passenger)	0.000460	t CO ₂ /km	Sreedhar et al., [9]

Table 8. Emission factor for material.

Activity	Emission Factor	Unit	Sources
Sand	0.0000025	t CO ₂ /kg	White et al., [3]
Concrete	0.1055000	t CO ₂ /t	White et al., [3]
	0.0001340	t CO ₂ /kg	Chen et al., [20]
Crusher run	0.0000026	t CO ₂ /kg	White et al., [3]
Wet-mix Roadbase	1.1400000	kg CO ₂ / t	Sreedhar et al., [9]
Prime coat	0.0001600	t CO ₂ /kg	Wang et al., [21]
	0.0205000	kg CO ₂ /m ²	Sreedhar et al., [9]
Dense Bitumen Macadam (DBM)	0.0786000	t CO ₂ /t	Sreedhar et al., [9]
	0.0238000	t CO ₂ /t	White et al., [3]
	0.0000630	t CO ₂ /kg	Chen et al., [20]
Binder course	0.0786000	t CO ₂ /t	Sreedhar et al., [9]
	0.0238000	t CO ₂ /t	White et al., [3]
	0.0000630	t CO ₂ /kg	Chen et al., [20]
Tack coat	0.0001600	t CO ₂ /kg	Wang et al., [21]
	0.0205000	kg CO ₂ /m ²	Sreedhar et al., [9]
Wearing course	0.0786000	t CO ₂ /t	Sreedhar et al., [9]
	0.0238000	t CO ₂ /t	White et al., [3]
	0.0000630	t CO ₂ /kg	Chen et al., [20]
Steel	0.0046700	t CO ₂ /kg	Sreedhar et al., [9]

Table 9. Result of carbon emission per unit activity from previous study.

Activity	Emission Factor	Unit	Sources
Clearance for road construction	0.006560	t CO ₂ /m ³	Sreedhar et al., [9]
Excavation with excavator	0.000539	t CO ₂ /m ³	Sreedhar et al., [9]
Construction of road sub-base	0.001140	t CO ₂ / t sub base	Wang et al., [21]
Rolling of layers, for one layer	0.000102	t CO ₂ /m ² compacted surface	Sreedhar et al., [9]
Prime coat	0.0000205	t CO ₂ /m ² applied surface	Sreedhar et al., [9]
Construction of road base course(unbound)	0.0011400	t CO ₂ /t roadbase	Sreedhar et al., [9]
Tack coat	0.0000205	t CO ₂ /m ² applied surface	Sreedhar et al., [9]
Paving of asphalt Layers, for one layer	0.0000965	t CO ₂ /m ² applied surface	Sreedhar et al., [9]
Rolling of asphalt layers, for one layer	0.0001300	t CO ₂ /m ² applied surface	Sreedhar et al., [9]

2.3. Calculation approach

According to report by National Corporate GHG Reporting Programmed for Malaysia, there are several approaches which could be taken in order to calculate carbon footprint [22]. For example calculations approach as show in table 10. Based on GHG Protocol, an organization should use the most accurate calculation approach available which is appropriate for their reporting. If it is not possible to calculate emissions from known activity data, the organization needs to estimate its emissions and extrapolate on the basis of known activity data.

Table 10. The calculation approach for calculating GHG Emissions [23].

No.	Calculation Approach	Description
1	Direct Measurement	- Monitor GHG concentration and flow rate - May be expensive and difficult to be implemented.
2	Stoichiometric Calculation	- Measure which elements enter and leave the system
3	Estimate emissions	- Most common approach for calculating GHG emissions - Apply documented emissions factors to known activity data from the organizations.

3. Comparison on the method whether using excel tool or Life Cycle Assessment (LCA) software

There are various tools for conducting LCA or for supporting the different phases and applications of LCA. Table 11 includes a list of existing LCA-related tools. Some main characteristics of the tools are included assessment on carbon footprint related to highway development, following the Carbon Footprint approach and IPCC guidelines for GHG emission assessment, consider all phase of development and activity, Carbon Offset, and result divided into scope. The summary of result from 21 case study as show in figure 1 below.

As also discussed in this report, there are many LCA methods and tools but not many is tailored for the highway development sector. Some difficulties in applying LCA in to highway development activity include the complexity of the methodology and lack of understanding.

Table 11. Comparison on the method.

Tool	Name	A	B	C	D	E	Reference
Excel Spreadsheet / Web Base	Highway England Carbon Tool	*	*	*			https://www.gov.uk/government/publications/carbon-tool
	Highways Agency Carbon Calculation For MAJOR PROJECTS	*	*				https://www.gov.uk/.../Major Projects HA Carbon Calculation Spreadsheet.xls
	Highways Agency Carbon Calculation For DBFOs	*	*				https://www.gov.uk/government/.../DBFO HA Carbon Calculation Spreadsheet.xls
	Carbon Footprint Calculator (develop by UTP)	*	*				Rozana Kasbon, et al., [24]
	Carbon Footprint Calculator Highway India	*	*				Sreedhar S. et al., [9]
	Defra / DECC's GHG Conversion Factors, UK	*	*			*	http://carboncalculator.direct.gov.uk/index.html
	Carbon Trust Standard Carbon footprint spreadsheet	*	*		*		https://www.carbontrust.com/.../carbon-trust-standard-carbon-footprint-spreadsheet.xls
	Direct Emissions	*	*				www.wri.org/sites/default/files/direct_emissions.xls
	Carbon Footprint	*	*		*		https://www.carbonfootprint.com/

	IESR Kalkulator Jejak Karbon, Indonesia	*	*			calculator.aspx http://www.iesr.or.id/kkv3/
	Resurgence Calculator	*	*			https://www.resurgence.org/resources/carbon-calculator.html
	Climatecare Carbon Calculator	*	*	*		https://climatecare.org/calculator/
Software	GaBi	*	*	*		http://www.gabi-software.com
	GEMIS	*	*	*		http://www.iinas.org/newsde.html , accessed: 21.02.2014
	openLCA	*	*	*		http://www.openlca.org
	SimaPro	*	*	*		http://www.pre-sustainability.com/software , accessed: 21.02.2014
	Umberto	*	*	*		http://www.umberto.de/en , accessed: 21.02.2014
	Spectrum IEEE	*				https://spectrum.ieee.org/static/carbon-calculator
	bp Carbon Calculator	*				http://www.bp.com/iframe.do?categoryId=9027929&contentId=7050956
	Safeclimate Calculator	*				http://www.safeclimate.net/calculator/
	MyFootprint Calculator	*				http://www.myfootprint.org/
	Number of tool	21	17	6	3	1

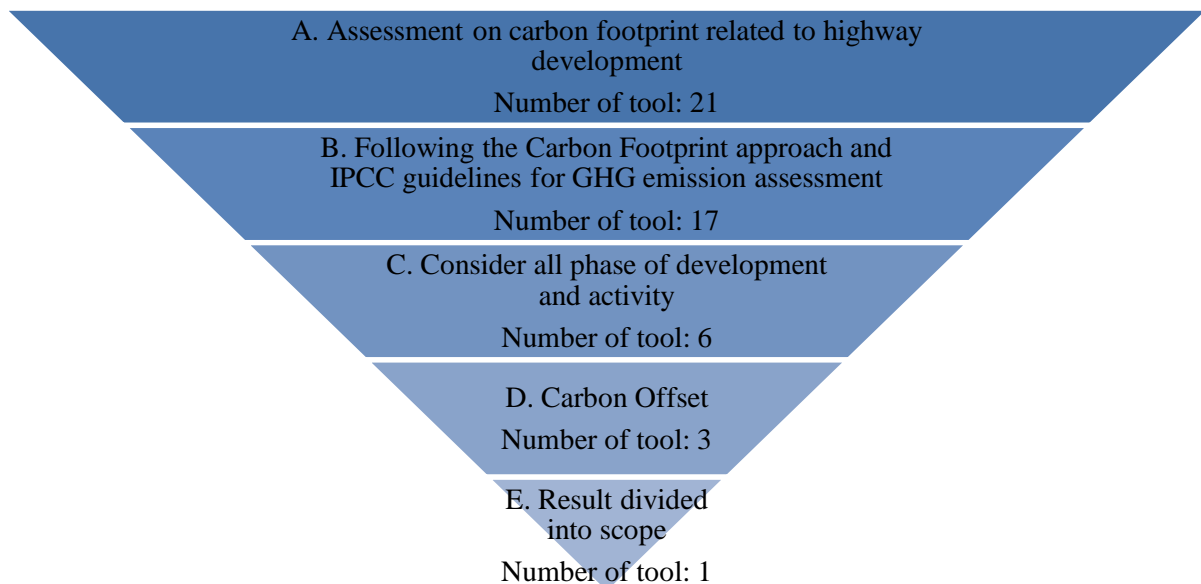


Figure 1. Application of carbon footprint calculation on highway development.

It is observed that using excel tool are better performance and easier to calculate and analysis the carbon footprint from many sources and stage compare than calculate using LCA software. Therefore, understanding the relationships between methods for calculate carbon footprint life cycle energy consumption and GHG emissions are critically important for highway agencies to evaluate their annual greenhouse gas emission reports.

4. Conclusion and recommendation

The Carbon Footprint Calculator can be established and implemented in Malaysia which can be the reference and guideline in the sustainable development of Green Highway. Besides, it also can be used as a highway development decision support tool in Malaysia.

In addition, the Carbon Footprint Calculator is developed specifically for the Malaysian tropical weather, environment, cultural and social needs. Thus, this research will be well contributed to the benefits of the nation especially towards the nation carbon reduction which believed to be achieve 45% reduction by the year 2030.

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