Journal of Civil & Environmental Engineering

Kar et al., J Civil Environ Eng 2015, 5:6
DOI: 10.4172/2165-784X.1000198

Research Article

Open Access

Estimation of Carbon Footprints of Bituminous Road Construction Process

Siksha Swaroopa Kar*, Ambika Behl, Anuradha Shukla and Pramod Kumar Jain

Central Road Research Institute, Delhi, India

Abstract

Carbon footprint is a term used to describe the total amount of carbon dioxide and other green house gas (GHG) emissions for which an individual/process/organization/activity is responsible. The challenge of global climate change has motivated state transportation agencies involved in the construction and maintenance of transportation infrastructure to investigate strategies that reduce the life cycle greenhouse gas (GHG) emissions associated with the construction and rehabilitation of highway infrastructure. The road sector is coming under pressure to review current practice and the potential to reduce carbon emissions. To reduce GHG emission, different approaches are adopted for road construction and maintenance such as Warm Mix and Cold Mix Technologies. Warm mix asphalt is produced at temperatures 20 to 40ºC lower than hot mix asphalt (HMA). Cold Mix Asphalt is produced and paved at ambient temperature using bitumen emulsion. The immediate benefit of producing and placing asphalt mixes at a lower temperature is the reduction in energy consumption, greenhouse gas emissions, fumes, and odours generated at the plant and the paving site. The life cycle approach has been accepted as a robust method of measuring carbon footprint. Tools and data-sets have been developed to facilitate the measurement. Among them is the Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads (CHANGER) developed by International Road Federation (IRF). This paper outlines the common methodology of road carbon foot printing, application of results in sustainable construction assessment schemes and resources available to undertake such analysis. Case studies of using CHANGER are provided in India for different technologies. The CO_2 output of these projects is compared.

Keywords: Bituminous; Carbon footprint; CHANGER; Hot mix; Warm mix

Introduction

The challenge of global climate change has motivated state transportation agencies involved in the construction and maintenance of transportation infrastructure to investigate strategies that reduce the life cycle greenhouse gas (GHG) emissions associated with the construction and rehabilitation of highway infrastructure [1]. Environmental consciousness is on the rise and many transportation officials are striving to make their practices and policies greener or more sustainable. To analyse the carbon footprint, one must look at the greenhouse gas (GHG) emissions associated with the construction and maintenance of a road. Greenhouse gases include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) etc. Greenhouse gas emissions are typically measured in terms of carbon dioxide equivalents (CO_2). Carbon Footprint of HMA and PCC Pavements [2], a paper presented at the 2009 International Conference on Perpetual Pavements, examined the carbon footprint of asphalt and concrete pavements for typical residential, collector, and freeway pavements constructed in Ontario, Canada. In addition, the paper looked at the carbon footprint of an equivalent asphalt freeway pavement built as a Perpetual Pavement. Both the carbon footprint of the initial construction and the carbon footprint of the maintenance activities over a 50-year life cycle were evaluated and compared.

Pavements cannot be easily defined as products. Pavement life cycle analysis (LCA) applications and methodologies have their roots in the application of traditional LCA methodologies that are typically product driven. In practice, it is difficult to assume a pavement section to be a well defined product with a standard functional unit. The functional lives of pavement control sections are less predictable unlike other typical products that have clearly defined functional lives. This comes out resulting with incomparable functionality, service lives and impacts. Most of the current research efforts in pavement LCAs emphasize prescriptive approaches that present general conclusions regarding the comparative impacts of pavement materials [3-6] based on estimated inventories and/or case studies. They have significantly furthered the field by illustrating the application of life cycle assessment methods. However, their conclusions are limited by explicit assumptions in the control sections selected for comparison, and implicit assumptions of uniform climate conditions, usage patterns and environmental contexts, such as access to raw materials and availability of local water resources. Regional and local variations are difficult to codify in these approaches, as they emphasize comparisons of alternative designs across assumed uniform conditions, rather than supporting context sensitive decisions that reduce long-term impacts. Often, there is limited consideration of construction process information, such as the type of equipment used and the impact of site location and layout when considering the total life cycle emissions. There has also been some disagreement on an appropriate functional unit. While the measures per lane mile have been commonly used, they are not completely representative. As the size of projects scale, such measures are subject to statistical smoothening resulting in flawed results. As an alternative, a recent study [7] has used representative panels of typical concrete and asphalt pavements to compare emissions of concrete and asphalt pavements. While not a perfect functional unit, this provides an approach to compare the emissions from a cluster of materials that are required to build a concrete panel and an asphalt panel respectively, and is arguably less sensitive to scale. A lack of consensus on these underlying definitions has plagued the pavement LCA literature. A recent review of pavement LCAs, by the Portland Concrete Association (PCA) [8], have reported inconsistencies due to functional units, improper system boundaries, imbalanced data for asphalt and cement, use of limited inventory and impact assessment categories, and poor overall utility. Efforts aimed

---

***Corresponding author:** Siksha Swaroopa Kar, Central Road Research Institute, Delhi, India, Tel: 011 2684 8917; E-mail: sikshaswaroopa@gmail.com

Received September 16, 2015; **Accepted** October 21, 2015; **Published** November 01, 2015

Citation: Kar SS, Behl A, Shukla A, Jain PK (2015) Estimation of Carbon Footprints of Bituminous Road Construction Process. J Civil Environ Eng 5: 198. doi:10.4172/2165-784X.1000198

at developing decision-support frameworks, to inform agency and stakeholder decisions, also remain fragmented. Prescriptive LCA frameworks have been developed to support decision making between broad pavement classes [9,10]. However, the assumptions underlying such frameworks often make them unsuitable for supporting policies that aim to reduce long-term GHG. They often lead to inaccurate generalizations that cannot be used to support context sensitive policy. In addition, they leave limited room for monitoring, and/or rewarding continuous improvement in construction planning processes aimed at reducing GHG. Subjective point based systems, such as GreenRoads™ [11], have been considered for reducing construction emissions. While such systems are easier to implement, they lack appropriate verification.

Studying pavement LCA framework accounts for the emissions from

(i) The mining, manufacturing and production of the material products (materials and equipment) used to construct the pavement,

(ii) The processes involved during the construction and maintenance of the pavement, and

(iii) The service life/use phase of the pavement. In doing so, the research builds on methods and metrics in the literature that apply LCA to different stages of the pavement's life.

Objective and Methodology

In this study, the greenhouse gas (GHG) emissions for overlaying of bituminous concrete were measured. The aim of this research is to compare the carbon footprint, defined as a composite measure of all GHG emissions expressed as equivalents of carbon dioxide emissions, between Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) using CHANGER Software. The methodology adopted for this study has been given in Figure 1.

Overview of CHANGER

CHANGER was developed by the International Road Federation (IRF) and the first version was released in November 2009. The model is being developed with a view to elaborate an IRF standard and certification. The goal of this tool is multifaceted [12]:

- To facilitate an environmental analysis of road projects;
- To provide a basis for the comparative analysis of various road laying techniques and materials;
- To optimise site supply schemes with respect to the choice of suppliers, delivery locations and transport modes;
- To enable an estimation of the carbon footprint of road construction activities.

The tool development, in partnership with Ammann, Colas and Scott Wilson (now URS), undertakes an iterative approach that includes data sourcing, initial analysis, feedback to data provider and revisit the calculation, in accordance with ISO 14044. The tool takes into account a range of emission sources during project life, and analyses at a project level to benchmark the carbon footprint per kilometre of road construction. The data-sets and the calculation have been validated by the Traffic Facilities Laboratory (LAVOC) of the Swiss Federal Institute of Technology [13,14] CHANGER adopts a typical process-based modelling approach (Figure 1). The calculation model is based on a set of equations that enable accurate estimation of overall GHG emissions (outputs) generated by each identified and quantified source [15]. Data will be sourced for the following activities:

- Preconstruction: site clearance, cut and fill, deforestation;
- Onsite energy (electricity, fossil fuels) consumption;
- Materials quantity;
- Transport mode and distance;
- Construction vehicles and equipments.

The carbon footprint of road projects comes mainly from three sources:

(1) Materials' embodied carbon dictated by the type and quantity, i.e., the manufacture and upstream processes, commonly referred to as 'cradle-to-gate' where the ICE data [16] is used by CHANGER, which is multiplied by the quantity of each type of material; (2) Carbon from transport vehicles that bring raw materials/products to plant/site or unserviceable materials to a place of disposal (e.g., recycling, stockpile, land fill). UK Department for Environment, Food and Rural Affairs (Defra) has standard emission factors for an array of payloads and fuel types [14], which is multiplied by tonnage and distance and (3) Carbon from construction activities (e.g., excavation, paving, rolling) that are calculated either for each individual process [10] or for a paving assembly as a whole (ECRPD 2010), which is multiplied by dimension/quantity of the field work. The effects of three GHGs have been considered in the calculation: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), all converted to the CO_2 equiv., using conversion factors provided by the Intergovernmental Panel on Climate Change [9]. A detailed description of CHANGER can be found on the IRF website [17]. The current version of the model does not include maintenance activities, provision and powering of street lighting, road signs and barriers, and impact associated with traffic using the road. The model does not account for the loss of CO_2 absorption by removal of trees or other land use change. CHANGER generates reports, either aggregated (total) or disaggregated (inherent to one or more steps of the process), that can be exported to Excel, Word, PDF and HTML.

The Case Study

The Project Road

The case study comprises of 62 km of a 4 lane highway with a width of 3.5 m at NH 62, Jodhpur Pali Road for each Warm Mix and Hot Mix. The total paved area is 1,798,000 m^2. 50 mm Bituminous Concrete (BC) specification was laid as binder course.

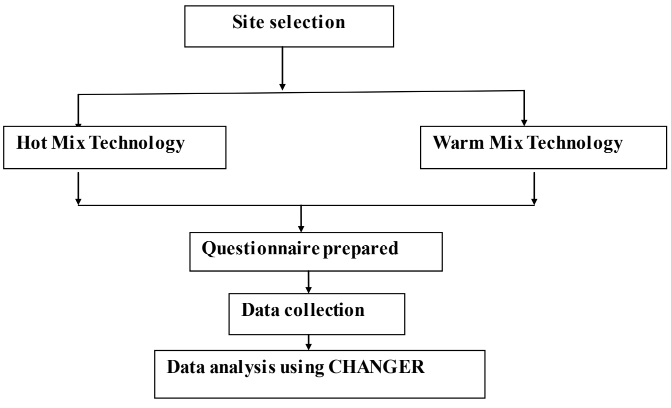

Figure 1: Flow chart of methodology.

Assessment of Carbon Dioxide Emission

Defining the scope of any work is an extremely important step. A well-defined scope makes the work accurate, easy to understand and enables better collection of data. Road construction is a large project consisting of various strata and process that are carried out. It is simply not possible that every aspect of the road construction to be included in the project, nor is it desirable. Too vast a scope can create problems in data collection, maintaining focus on the primary subject matter and can introduce inaccuracies and ambiguities.

For this particular study, scope of the work is defined as follows and is shown in Figure 2.

- The boundary is restricted to the region above the base soil. Also any kind of embankment shoulders or road furniture such as toll plazas, markers, sign boards, rails etc will be excluded.
- The focus will mainly be on the process carried out in the construction of the road and the material used for making the layers of the road
- Any road furniture will be excluded and hence no calculations for the Greenhouse emissions from the process carried out during the production of such materials will be made.

Collection of data and questionnaire

As per the parameter defined in software CHANGER, the data was collected from the site while the laying of the section. Warm Mix Asphalt was produced at 130°C using a surfactant based warm mix additive. Binder was used VG 30 for Hot Mix Asphalt (HMA). HMA was produced at 160°C. Warm Mix section compaction was done at 110°C while for HMA compaction was achieved at 150°C. The aggregates used for the project were collected from a local quarry about 8-10 km away, contributing towards lesser emission during transportation. Binder was received from HPCL, Mumbai Plant around 910 km away from site.

Results and Discussion

Analysis through CHANGER

The data collected from the site was analysed through CHANGER. Preconstruction parts and onsite impacts have not been analysed. The construction equipment used and transport of material for both the site is same. The saving of CO2 emission using Warm Mix Technology over Hot Mix Technology is only due to the reduction of temperature during mixing. Near about 590 tonne equivalent C0$_2$ is saved for 1,798,000 m^2 paving area i.e., 32 gm /1 m^2 paving area. Using Warm Mix Technology, GHG emission in terms of equivalent to C0$_2$ reduces by 32 gm per 1 m^2 paving area. For the total project 590 tonne of CO$_2$ emissions were saved. The embodied energy of material plays a vital part in emissions which includes hot mix plant emission. Construction machine has negligible effect (0.02%) on the total emission. The Figure 3 shows the effect of component on the total emission from the project (Table 1).

WMA		HMA	
Consolidated results:	**tCO$_2$-eq**	**Consolidated results:**	**tCO2-eq**
Construction materials:	17390.0	Construction materials:	17980.0
Material transport:	9482.8	Material transport:	9482.8
Construction machines:	6.1	Construction machines:	6.1
Total CO$_2$ equivalent emissions:	**26,878.70**	**Total CO2 equivalent emissions:**	**27,469.14**

Table 1: Consolidated results of Emission from WMA and HMA.

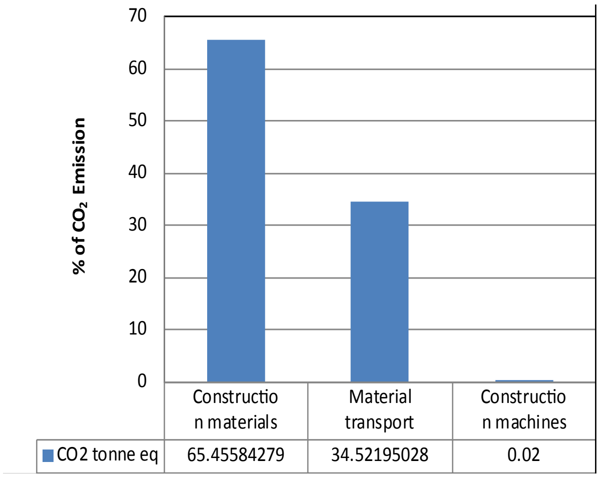

Figure 3: Effect of component on the total emission from the project.

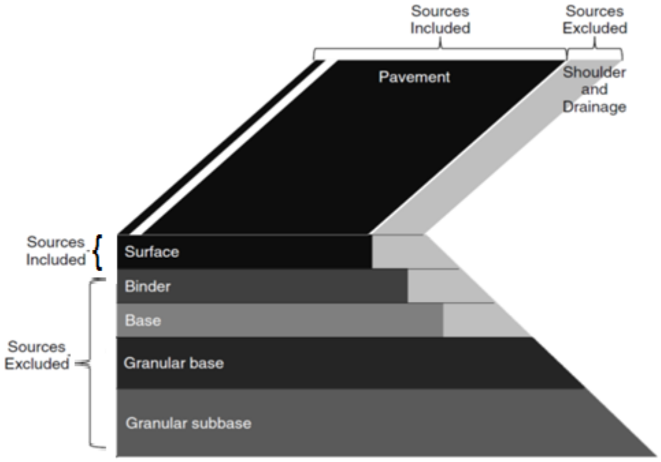

Figure 2: Scope of work presented in the paper.

Conclusion

The IRF developed software “CHANGER” is a very good tool that enables assessment of GHG emission arising out of road construction activity. This handy tool has opened a huge possibility in analysing the various design possibilities and selection of materials based on location and transportation of material. There is a further need for more comprehensive case studies that include more materials and more accurate quality checks on assumption necessary for estimating the amount consumed for the most important materials.

Acknowledgement

The authors would like to thank Dr. S. Gangopadhyaya Director CSIR-Central Road Research Institute, New Delhi for permission to publish this paper. The authors would also like to thank M/s MWM Pvt. Ltd. that they help in getting the data from the site.

References

1. Santero N, Harvath A (2009) Global warming potential of pavements. Environ Res Letters 4, p. 034011.
2. Alexander B (2009) Carbon Footprint of HMA and PCC Pavements. P Int Conference on Perpetual Pavements, Columbus, Ohio.
3. Muga H (2009) An integrated assessment of continuously reinforced and jointed plain concrete pavements. J Eng Design and Technol 7: 81-98.

4. Gambatese JA, Rajendran S (2005) Sustainable Roadway Construction: Energy Consumption and Material Waste Generation of Roadways. San Diego, California, pp. 21-21.
5. Zapata P, Gambatese JA (2005) Energy Consumption of Asphalt and Reinforced Concrete Pavement Materials and Construction. J Infrastruct Systems 11, pp. 9-20.
6. Horvath A, Hendrickson C (1998) Comparison of Environmental Implications of Asphalt and Steel-Reinforced Concrete Pavements. Transportation Research Record: Journal of the Transportation Research Board 1626, pp. 105-113.
7. Gallivan F (2010) Greenhouse Gas Mitigation Measures For Transportation Construction, Maintenance, and Operations Activities. ICF International. Inc.
8. Santero N (2010) Life Cycle Assessment of Pavements: A Critical Review of Existing Literature and Research. Portland Cement Association2010.
9. Guggemos AA, Horvath A (2006) Decision-Support Tool for Assessing the Environmental Effects of Constructing Commercial Buildings. J Arch Eng 12, pp. 187-195.
10. Horvath A (2004) Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE). ed: Recycled Materials Resource Center.
11. Muench S (2010) Greenroads: A Sustainability Rating System for Roadways. Int J Pavement Res Technol 3, pp. 207-279.
12. Zammataro S (2011) Assessing greenhouse gas emissions in road construction: an example of calculation tool for road projects. PIARC Seminar On Reducing The Carbon footprint In Road Construction, 17–19 February 2011, New Delhi, India.
13. Dumont N (2009) IRF greenhouse gas calculator – analysis and validation. Traffic Facilities Laboratory, Swiss Federal Institute of Technology.
14. IRF (2007) Green path to climate neutral roads. World Highways November/December 2007, International Road Federation, pp. 22–23.
15. Stripple H (2001) Life cycle assessment of road – a pilot study for inventory analysis. Swedish Environmental Research Institute (IVL).
16. IPCC (2007) 4th assessment report- the physical science basis. Intergovernmental Panel on Climate Change.
17. http://www.irfghg.org/index.php