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Investigation of Carbon Footprints of Highway Construction Materials in India

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Abstract

With increasing urbanization and living standards of people in India, there is certainty that there will be a substantial increase in human activities such as transportation infrastructure development, and associated rise in energy demand. Thus, it is imperative that the technical knowhow regarding carbon emissions due to roadway infrastructure is advanced further to accomplish a sustainable environment. Thus, the objective of this research study was to develop a toolkit termed “Carbon Footprint Calculator” to quantify the carbon footprints of the different pavement systems used in highway construction. The tool developed as part of the study incorporated the major contributors of Greenhouse Gas (GHG) emissions including: pavement design aspects; material production and transportation from source to site; construction practices used in the various pavement systems and the expected vehicular operations during the pavement design life. A mathematical model to estimate the overall amount of GHG emissions in terms of total $kgCO_2$ equivalent ($kgCO_2e$) was also developed as a part of this study. In this study, the evaluation of GHGs in terms of carbon footprints for the different pavement systems used in Indian roadway construction was approached from a life cycle assessment perspective. It is envisioned that this tool could be well-utilized by design engineers to optimize pavement design methodology and construction practices in respect of creating a greener sustainable environment.

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Keywords: Greenhouse Gases (GHG), $kgCO_2$ equivalent, Carbon footprints, Life cycle analysis, Carbon footprint calculator

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1. Introduction

With an increase in India's population growth, the rate of urbanization and industrialization will also increase substantially with a need for higher energy and resource consumption. This increase in urbanization and industrialization would also generate higher demand for infrastructure development and associated work. The Intergovernmental Panel for Climate Change (IPCC) estimates that the transportation sector annually produces 13% of the total greenhouse gas (GHG) emissions at the global level (IPCC Climate Change (2007)). India ranks third in the annual carbon dioxide (CO_2) emissions, which comprises of 6% of emissions worldwide. Of this, the contribution of the transportation sector to CO_2 emissions is about 161 million metric Tonnes(World Bank IBRD.IDA). Therefore, it is critical that with an increasing economy and population in this country, concrete steps are necessary to commensurate with the pace of development; albeit without compromising on the international emission standards.

In this context, the need of the hour is to understand the CO_2 indicators with respect to roadway infrastructure and construction related aspects. Although many of the past studies were based upon Life Cycle Analysis (LCA) approach, it is also noteworthy that these investigations were largely confined to the pavement materials used during construction, placement and maintenance phases as well as in the design life time-frame of the pavement systems (Huang (2007); White et al. (2010); Hanson et al. (2012); Barandica et al. (2013)). Additionally, studies have indicated that construction of pavement structures contribute to only about 10% or lower of the total GHG emissions, whereas the findings indicated that the majority of the emissions are attributed from the vehicular movements during pavement lifetime (Häkkinen and Mäkelä (1996); Inamura(1999)).

In the context of the estimations of the CO_2 emissions indicators pertinent to highway construction, there is limited research which focuses on the pavement design traffic aspects during the life cycle of an entire roadway construction project. Hence, there is a need to develop a study methodology that incorporates the construction stages of a roadway project, pavement design and traffic parameters in order to comprehensively assess the changes in GHG emission levels.

2. Objective and scope

The main objective of this study was to develop a computer program toolkit to quantify the carbon footprints of the different pavement systems used in highway construction. The tool developed as part of the study incorporated the major contributors of GHG emissions including: pavement design aspects; material production and their transportation from source to site; construction practices used in the various pavement systems and the expected vehicular operations during the pavement design life. Finally a mathematical model was developed which can be directly used to estimate the overall amount of GHG emissions in terms of total $kgCO_2$ equivalent (designated in this paper as $kgCO_2e$). This tool was eventually used to estimate the overall amount of GHG emissions in terms of total $kgCO_2$ equivalent (designated in this paper as $kgCO_2e$). The scope of the research study encompassed: (i) literature review to understand the contribution of the various factors responsible for calculation of carbon footprints and related terms, pertinent to roadway construction projects in India considering life cycle analysis approach and modeling technique; (ii) formulation of a robust and innovative methodology framework incorporating the various stages of construction of roadway infrastructure, including the pavement design factors; (iii) definition of a project as per Indian specifications related to the construction materials, equipment, stages, and pavement design and traffic parameters considering both flexible and rigid pavement systems; (iv) development of a computer tool that evaluates and estimates the total carbon footprints (overall $kgCO_2e$) for different pavement systems; and (v) comparison and analyses of the different combinations of materials, and investigation of their relative effects on the overall $kgCO_2e$.

3. Background

This section documents the important concepts and techniques related to the various terms related to calculation of the carbon footprints corresponding to highway construction. Only important concepts will be discussed for brevity purposes, including: GHG emissions, global warming potential (GWP), CO_2e, carbon footprints, and life cycle approach to estimate the GHG emissions for roadway projects.

3.1. Greenhouse Gases (GHG)

The gases that trap heat in the atmosphere are called greenhouse gases (and abbreviated as GHG). These are the gases which are responsible for the continuous increase in the global atmospheric temperatures. The four major contributors to this effect are carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O) and fluorinated gases.

3.2. Global Warming Potential (GWP)

The ability of various GHGs to trap heat based on the absorbing ability of each gas in the atmosphere and defined over a specified time period is called GWP of the particular gas. The time period specified corresponds to the change in the relative damage of the gas over time and can be 20, 100 or 200 years; but for standard purposes, 100 years is taken as a base period (Global greenhouse warming (2014)). The basic purpose of using the GWPs is to convert individual GHGs to CO_2e i.e., a standard format for reporting global emissions.

3.3. CO_2 Equivalent (CO_2e)

It is used as a metric measure used to compare the emissions from various GHGs based upon their global warming potential (GWP). CO_2 is taken as a reference for calculation of overall emissions because almost all of the materials contain the basic element as carbon, which on oxidation produces CO_2; and it is also the most prevalent GHG present in the atmosphere. Although CO_2 and CO_2e are interrelated, they are distinct measures for calculating the global emissions. The carbon dioxide equivalent for a gas is derived by multiplying the Tonnes of the gas by the associated GWP:

$$\text{kgCO}_2\text{e} = (\text{Amount of a gas in kg}) * (\text{GWP of the gas}) \tag{1}$$

3.4. Carbon Footprints

A carbon footprint measures the total GHG emissions caused directly by a person, organization, event or product. The total GHG emissions caused directly and indirectly by an individual, organization or product is expressed as a CO_2e. A carbon footprint accounts for six Kyoto GHG emissions, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs) and sulfur hexafluoride (SF_6) (Kyoto Protocol Reference Manual(2008)). Over the last several years, calculations of carbon footprints have gained more importance due to the fact that the environmental norms and conditions specify a particular amount of CO_2 emissions for various activities.

3.5. Life Cycle Analysis (LCA) approach

There are two ways of calculating carbon footprint for a particular item: the first approach deals with the organizational carbon footprint which includes the emissions for the commodity by its own activities (supply change, and manufacturing, etc.) whereas the second approach deals with the product carbon footprint which deals with all the direct and indirect emissions by different activities (during the whole life cycle). The product carbon footprint is estimated by using the LCA approach (Carbon Trust (2014)). Life-cycle assessment is a technique to assess environmental impacts associated with all the stages of a product’s life from-cradle-to-grave i.e., from raw material extraction, materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. LCA is a tool widely used to support business strategy and strengthen research and development related to environmental concern.

4. Study methodology

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

- Pavement design
- Production of raw materials
- Transport of raw materials from source to site
- Various construction stages (land clearance, pre-paving, paving and post-paving)
- Construction equipment used in the process
- Maintenance and rehabilitation
- Opening the facility to the traffic

Of the aforementioned stages, the maintenance and rehabilitation stage was not considered in this study because of the unavailability of data. Also, the structures involved in a road construction project such as culverts, bridges, truck/bus bays and roadside furniture were not a part of this study.

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.

Table 1 provides a summary of the various components used for the development of the model to estimate the kgCO_2e produced by the facility from very reliable sources. As presented, the data for the various processes along with their energy consumption were acquired from a high quality inventory data of Swedish origin (Stripple (2011)). The CO_2 equivalency factors shown in the summary for the various activities was compiled based upon the various research papers, industry standards and governmental environment reports (White et al. (2010); Kyoto Protocol Reference Manual (2008); Stripple (2011); Ramachandra, and Shwetmala (2009)).

Table 1.Equivalent kgCO2e for various Components, Materials and Processes

Component	Value	Unit	Source
Production			
Aggregates	0.0028	kgCO_2e/kg	White et.al. (2010)
Lime	2.81	kgCO_2e/kg	Stripple(2011)
Bitumen	0.426	kgCO_2e/kg	White et.al. (2010)
Cement	0.8207	kgCO_2e/kg	White et.al. (2010)
Fly Ash	-	kgCO_2e/kg	
Steel	4.67	kgCO_2e/kg	Stripple (2011)
Material Movement			
Truck Transport (14 Tonnes)	1.1	kgCO_2e/(vehicle*km)	Stripple (2011)
Construction Stages			
Clearance for road construction	6.56	kgCO_2e/m^3	Stripple (2011)
CO_2 emission due to permanent reduction of biomass	1540	kgCO_2e/m^3	
Excavation with excavator	0.539	kgCO_2e/m^3	
Construction of road sub-base	1.14	kgCO_2e/Tonne sub-base	
Rolling of layers, for one layer	0.102	kgCO_2e/m^2 compacted surface	
Prime Coat	0.0205	kgCO_2e/m^2 applied surface	
Construction of road base course(unbound)	1.14	kgCO_2e/Tonne base course	
Rolling of layers, for one layer	0.102	kgCO_2e/m^2 compacted surface	
Tack Coat	0.0205	kgCO_2e/m^2 applied surface	
Production of hot asphalt	78.6	kgCO_2e/Tonne asphalt	
Paving of asphalt Layers, for one layer	0.0965	kgCO_2e/m^2 applied surface	
Rolling of asphalt layers, for one layer	0.130	kgCO_2e/m^2 applied surface	
Design Traffic			
LMV (Goods)	0.914	kgCO_2e/ km	Ramachandra, Shwetmala (2009)
LMV (Passenger)	0.460	kgCO_2e/ km	Ramachandra, Shwetmala (2009)

Using the aforementioned parameters of interest, a spreadsheet computer tool using the Microsoft® Excel platform was developed designated "Carbon Footprint Calculator" with various modules that correspond to different stages of the roadway construction project to estimate the total kgCO_2e for any pavement system of interest. The tool developed could be used to estimate the emissions for both HMA and PCC pavement systems simply by inputting the relevant parameters appropriately.The description of the five modules of the computer tool is as follows.

4.1. Module 1: Input/output Interface:

In this module, the project details are the basic inputs. Also, information such as: type of pavement and roadway facility, length and width of the facility, thickness of the pavement system, design life, shoulders and service roads are entered. Thus module provides an overall input-output interface for the project as shown in Figure 1.

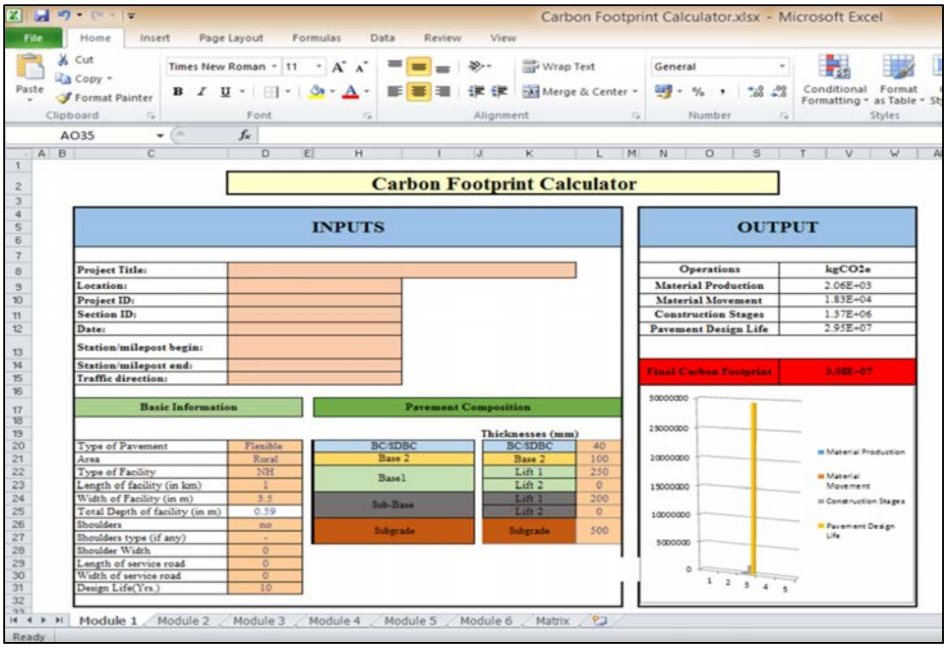


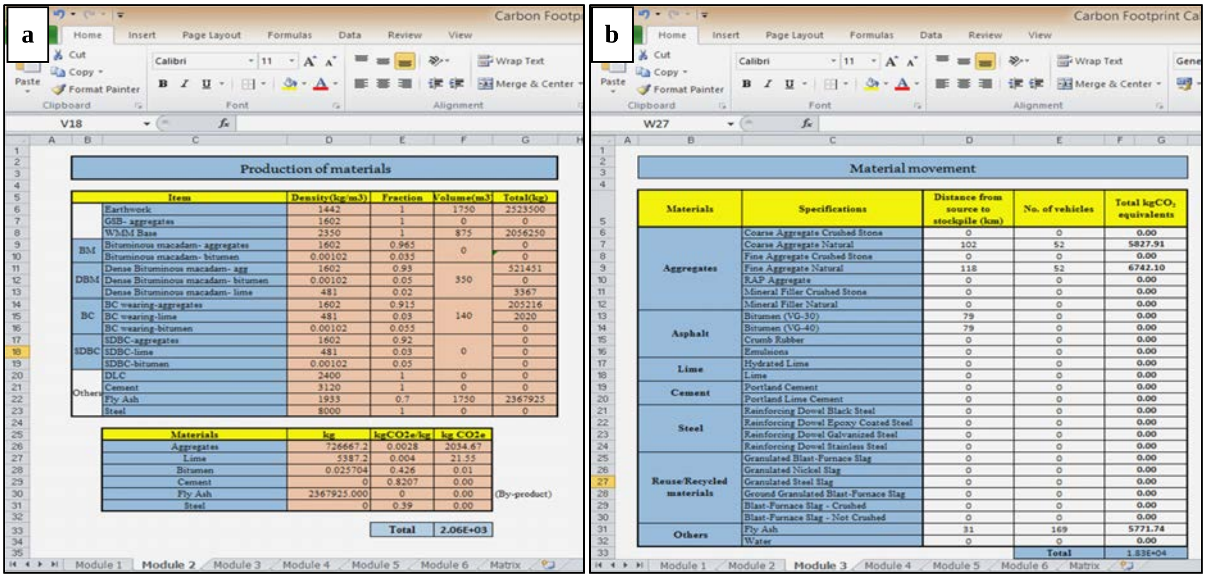
Fig. 1.Module 1 - Input/output Interface.

4.2. Module 2: Material Production:

In this module, based upon the roadway materials inputs and cross-sectional details, the corresponding volumetrics for each material and layer are calculated using the provided default densities and the proportion of the materials in each layer. However, the user can modify the materials and their properties appropriate to the construction project as shown in Figure 2(a).

4.3. Module 3: Material Movement:

This module focuses on the distances covered during transport of different materials from the source to the site (in km) and the number of vehicles required to undertake the material movement as shown in Figure 2(b). The user is free to input the distances of the material transport. As a direct calculation, from the total volume of the construction materials produced in a particular project, the program estimates the number of vehicles required to transport these materials from the source to the site.



a

Production of materials

Item		Density(kg/m3)	Fraction	Volume(m3)	Total(kg)
	Earthwork	1442	1	1750	2523500
	GSB- aggregates	1602	1	0	0
	WMM Base	2350	1	875	2056250
BM	Bituminous macadam- aggregates	1602	0.965	0	0
	Bituminous macadam- bitumen	0.00102	0.035		0
DBM	Dense Bituminous macadam- agg	1602	0.93	350	521451
	Dense Bituminous macadam- bitumen	0.00102	0.05		0
	Dense Bituminous macadam- lime	481	0.02		3367
BC	BC wearing-aggregates	1602	0.915	140	205216
	BC wearing-lime	481	0.03		2020
	BC wearing-bitumen	0.00102	0.055		0
SDBC	SDBC-aggregates	1602	0.92	0	0
	SDBC-lime	481	0.03		0
	SDBC-bitumen	0.00102	0.05		0
Others	DLC	2400	1	0	0
	Cement	3120	1	0	0
	Fly Ash	1933	0.7	1750	2367925
	Steel	8000	1	0	0

Materials	kg	kgCO2e/kg	kg CO2e	
Aggregates	726667.2	0.0028	2034.67	
Lime	5387.2	0.004	21.55	
Bitumen	0.025704	0.426	0.01	
Cement	0	0.8207	0.00	
Fly Ash	2367925.000	0	0.00	(By-product)
Steel	0	0.39	0.00	
		Total	2.06E+03	

b

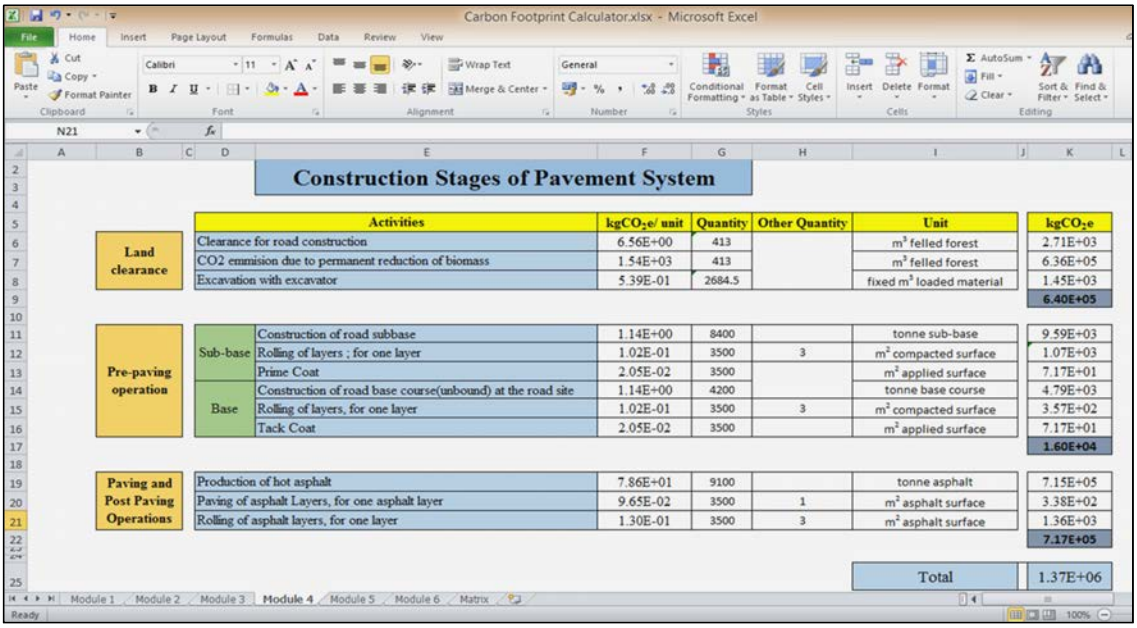
Material movement

Materials	Specifications	Distance from source to stockpile (km)	No. of vehicles	Total kgCO$_2$ equivalents
Aggregates	Coarse Aggregate Crushed Stone	0	0	0.00
	Coarse Aggregate Natural	102	52	5827.91
	Fine Aggregate Crushed Stone	0	0	0.00
	Fine Aggregate Natural	118	52	6742.10
	RAP Aggregate	0	0	0.00
	Mineral Filler Crushed Stone	0	0	0.00
	Mineral Filler Natural	0	0	0.00
Asphalt	Bitumen (VG-30)	79	0	0.00
	Bitumen (VG-40)	79	0	0.00
	Crumb Rubber	0	0	0.00
	Emulsions	0	0	0.00
Lime	Hydrated Lime	0	0	0.00
	Lime	0	0	0.00
Cement	Portland Cement	0	0	0.00
	Portland Lime Cement	0	0	0.00
Steel	Reinforcing Dowel Black Steel	0	0	0.00
	Reinforcing Dowel Epoxy Coated Steel	0	0	0.00
	Reinforcing Dowel Galvanized Steel	0	0	0.00
	Reinforcing Dowel Stainless Steel	0	0	0.00
Reuse/Recycled materials	Granulated Blast-Furnace Slag	0	0	0.00
	Granulated Nickel Slag	0	0	0.00
	Granulated Steel Slag	0	0	0.00
	Ground Granulated Blast-Furnace Slag	0	0	0.00
	Blast-Furnace Slag - Crushed	0	0	0.00
	Blast-Furnace Slag - Not Crushed	0	0	0.00
Others	Fly Ash	31	169	5771.74
	Water	0	0	0.00
			Total	1.83E+04

Fig. 2.(a)Module 2 - Material Production (b)Module 3 - Material Movement

4.4. Module 4: Construction Stages in a Pavement System:

This module considers three major stages during the construction of a pavement system, namely: (a) Land Clearance; (b) Pre-Paving Operations; (c) Paving and Post-Paving Operations. Under these elements, various processes of the activities are involved, which will be illustrated in Figure 3. The estimators involved in this module are the kgCO2e per element (stage) in the process for different units of the components.



Construction Stages of Pavement System

		Activities	kgCO$_2$e/ unit	Quantity	Other Quantity	Unit	kgCO$_2$e
Land clearance		Clearance for road construction	6.56E+00	413		m^3 felled forest	2.71E+03
		CO2 emmision due to permanent reduction of biomass	1.54E+03	413		m^3 felled forest	6.36E+05
		Excavation with excavator	5.39E-01	2684.5		fixed m^3 loaded material	1.45E+03
							6.40E+05
Pre-paving operation	Sub-base	Construction of road subbase	1.14E+00	8400		tonne sub-base	9.59E+03
		Rolling of layers ; for one layer	1.02E-01	3500	3	m^2 compacted surface	1.07E+03
		Prime Coat	2.05E-02	3500		m^2 applied surface	7.17E+01
	Base	Construction of road base course(unbound) at the road site	1.14E+00	4200		tonne base course	4.79E+03
		Rolling of layers, for one layer	1.02E-01	3500	3	m^2 compacted surface	3.57E+02
		Tack Coat	2.05E-02	3500		m^2 applied surface	7.17E+01
							1.60E+04
Paving and Post Paving Operations		Production of hot asphalt	7.86E+01	9100		tonne asphalt	7.15E+05
		Paving of asphalt Layers, for one asphalt layer	9.65E-02	3500	1	m^2 asphalt surface	3.38E+02
		Rolling of asphalt layers, for one layer	1.30E-01	3500	3	m^2 asphalt surface	1.36E+03
							7.17E+05
						Total	1.37E+06

Fig. 3.Module 4 - Construction Stages in a Pavement System.

4.5. Module 5: Pavement Design Traffic:

This module mainly targets estimation of $kgCO_2e$ per km of the actual traffic counts during the whole design life of a pavement system. In simple words, from the initial traffic data collected for the design of different roadway stretches, the total predicted vehicles operating on the facility over the entire design life can be found. In calculations, this number of vehicles will be assumed to be using the facility before any rehabilitation or major maintenance work is carried out. Hence, the emissions by these vehicles need to be considered in the life cycle of a pavement segment (and a pavement system within that segment). The module was so prepared in order to incorporate the missing constituent in the overall $kgCO_2e$ in a roadway construction project as explained in the project statement and objective. Thus, the use of the robust traffic prediction and design factors such as initial traffic, growth rate, Vehicle Damage Factor (VDF), Lane Distribution Factor (LDF), and percent trucks or number of commercial vehicles using the facility were utilized in the estimation of number of standard axles and the final $kgCO_2e$ applicable to the pavement design life with traffic as a major component a shown in Figure 4. In essence, the emissions caused by commercial and non-commercial vehicles collectively estimated will contribute to the overall traffic constituent in the LCA of the pavement system.

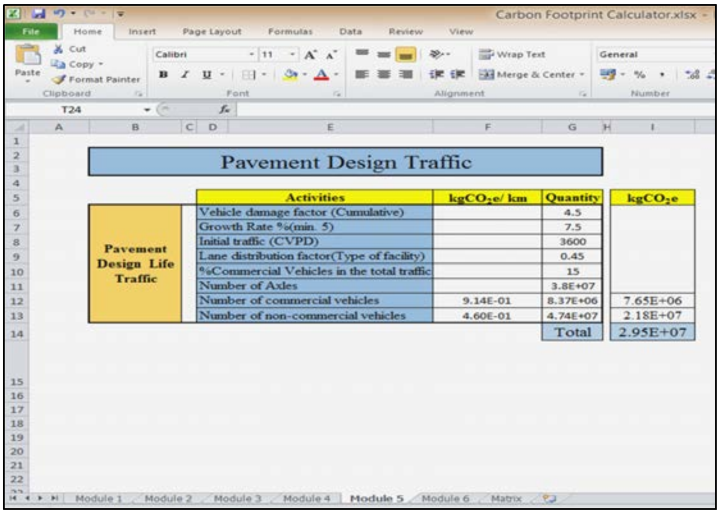


Fig. 4.Module 5 - Pavement Design Traffic.

One of the tasks of this study was to conglomerate all the components of the individual modules into a single mathematical formulation in the form of a predictive equation to estimate Carbon Footprint of any pavement system in a roadway infrastructure construction project. Based upon the components enlisted in the previous section on the methodology, the total kgCO2e estimated using in the tool is given by:

$$\text{Total kg } CO_2e. = (W \times 1000) \sum_{i=1}^{n} \left\{ t_i \left[\left(D_i \times \frac{P_{n,i}}{1000} \right) + (S_d \times M_n) + \left(D_i \times \frac{C_{c,i}}{1000} \right) + (C_{r,i}) + \%F \times (C_{cl} + C_p) + (C_{ex}) \right] \right\} + \frac{N_f}{VDF} \left[(\%T_r \times T_{cv}) + \left((1 - \%T_r) \times T_{ncv} \right) \right] \quad (2)$$

Where:

- W Width of the road, m
- t_i Thickness of the i^{th} layer, m
- D_i Density of the i^{th} layer, kg/m^3
- $P_{n,i}$ Production value, kg CO_2e/Tonne
- S_d Distance between site and source, km

M_n Material movement value, kg CO_2e/m^3,km
$C_{c,i}$ Construction value of ith course, kg CO_2e/Tonne
$C_{r,i}$ Rolling value of ith course, kg CO_2e/m^2
N_f Cumulative standard axles, Million Standard Axle
VDF Vehicle damage factor
$\%T_r$ Percent trucks, %
T_{cv} Commercial vehicle emission, kg CO_2e/km
T_{ncv} Non-commercial vehicle emission, kg CO_2e/km
%F % area of forest felled
C_{cl} Land clearance emission, kg CO_2e/m^2
C_p Permanent reduction of biomass due to felling of trees in a forest, kg CO_2e/m^2
C_{ex} Excavation of landmass for the project, kg CO_2e/m^3

Note that this mathematical model is also housed within the computer program, whose utilization is provided next.

5. Estimation of carbon footprints for asphalt and concrete pavements:

The “Carbon Footprint Calculator” tool was used to estimate the carbon footprints of the flexible and rigid pavement systems during the various stages of construction. Furthermore, the tool was used to test for the rationality and reliability of the underlying principles of the modules in the program. It is noteworthy that this tool can provide a base for assessing the individual units and also the overall effects between the various options. The mix designs for the different pavement layers considered in the analyses were chosen conforming to the Government of India’s Ministry of Road Transport and Highways (MoRTH (2001)) specifications. The following inputs were used to study the overall emissions in terms of kgCO_2e for a roadway construction project:

- Length of facility : 1 km
- Width of facility : 3.5 m
- Total depth of facility : 0.59 m
- Design Life : 10 years
- Design Traffic in Million Standard Axles : 38 msa
- Average Distance of source to site : 50 km
- Vehicle Damage Factor (VDF) : 4.5
- Lane Distribution Factor (LDF) : 0.45 (IRC 37:2012)
- Pavement Composition and density:
  - Subgrade : 500 mm [1442 kg/m^3]
  - Sub-base- Granular Sub-base (GSB) : 200mm [1602 kg/m^3]
  - Base: Wet Mix Macadam (WMM) : 250 mm [2350 kg/m^3]
  - Binder Course: Dense Bituminous Macadam(DBM) : 100mm
  - Wearing Course: Bituminous Concrete (BC) : 40mm
  - Dry Lean Concrete (DLC) : 200mm
  - Portland Cement Concrete (PCC) : 350mm

In the present study, the assumptions and values considered in the tool are based upon the various reliable references stated before, and also according to the various Indian specifications as below:

- Densities of materials (kg/m^3): Aggregates-1602; Bitumen-0.00102; Lime-481; Fly Ash-1933; Cement-3120
- DBM Grade 1 (MoRTH, 2001): 5% bitumen; 2% lime; and 95% aggregates
- BC: 5.5% bitumen; 3% lime; 91.5% aggregates
- GSB: Grade 1 (MoRTH, 2001)
- The truck considered for transport of materials was a 14 Tonne capacity loader with emissions of 1.1 kgCO_2e per vehicle per km.

- Land Clearance: The percent forest cover for the area of work was considered as 20%. The loose material after excavation was taken as 1.3 times the actual volume.
- Densities of the sub-base, base, Hot-Mix Asphalt (HMA) and Dry Lean Concrete (DLC) courses were respectively, 2400, 1200, 2600 and 2400 kg/m^3.
- Traffic growth rate was assumed as 7.5% and the commercial vehicles in total operating traffic were 15%.

6. Results & discussion

The total kgCO_2e estimated for the different pavement systems were compiled and tabulated as shown in Table 2. The relationships showing the variations of the total kgCO_2e for the various stages of the different pavement types and systems are depicted in Figure 5. As observed, there was an insignificant change in the overall emissions in the flexible asphalt pavements though different combinations in the mix designs were tried. However, for the rigid cement concrete (PCC) pavement system, it was observed that the material production values were higher than that of flexible pavements owing to the fact that cement production itself produces substantially higher level of emissions (1.37 x 10^6 for cement concrete versus 2.06 x 10^3 for bituminous concrete pavement). Furthermore, the material movement and construction operations of rigid pavement system produced lower emissions than the flexible pavements chiefly due to higher energy required during asphalt mixing and compaction. Overall, the emissions for the rigid concrete pavements were found to be greater than the flexible asphalt pavement structures (approximately, a differential of 25% between the two pavement systems).

Table 2: Stage-wise kgCO_2e emissions for various materials

Material Used	Material Production	Material Movement	Construction stages	Traffic design life	Total
Bituminous Concrete	2.06E+03	1.83E+04	1.37E+06	2.95E+07	3.09E+07
Semi Dense Bituminous Concrete	2.06E+03	1.84E+04	1.37E+06	2.95E+07	3.09E+07
Dense Bituminous Macadam	2.06E+03	1.84E+04	1.37E+06	2.95E+07	3.09E+07
Bituminous Macadam	2.12E+03	1.89E+04	1.37E+06	2.95E+07	3.09E+07
Portland Cement Concrete	1.37E+06	1.42E+04	6.81E+05	3.68E+03	3.89E+07

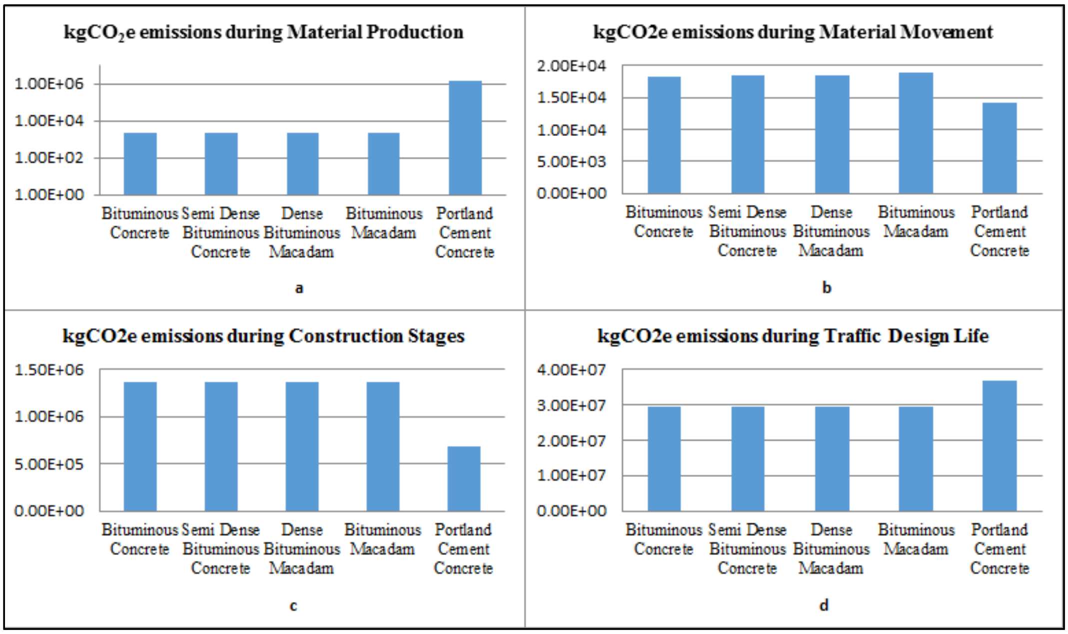


Fig. 5.Effect of change in materials on kgCO_2e

7. Conclusions & recommendations

The main objective of this study was to develop a computer program toolkit called “Carbon Footprints Calculator” to quantify the carbon footprints of the different pavement systems used in highway construction. The Carbon Footprints Calculator housed the various highway construction stages, including: material production and transportation, and specifically, pavement design traffic parameters to estimate the total kgCO_2e for different pavement systems used commonly in Indian roadway construction projects. A study was carried out to test the reliability and rationality of the tool by changing the various pavement materials and it was found that the there was an insignificant change in the overall emissions in the flexible pavements compared to the rigid ones. Furthermore, it was also evident that rigid concrete pavements produced higher kgCO_2e than flexible pavements owing to the fact that the production of cement in itself is much higher than that of flexible pavements. It is worth noting that this study considered a very important aspect in the overall lifecycle of pavement system during construction that was not used in prior research studies: traffic design parameter. However, other LCA parameters such as rehabilitation and maintenance must also be incorporated in future to get comparable estimates of kgCO_2e between the different sustainable highway infrastructure facilities.

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