Carbon Footprint of Roads: A Literature Review

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***Abstract* - Globalization and liberalization policies of the government of India have increased the number of roads and vehicles playing on them. These vehicles mainly consume non-renewable fossil fuels, and are a major contributor of greenhouse gases, particularly CO_2 emission. The intensification of Carbon emissions of road construction sector has strived transportation agencies involved in the construction and maintenance of transportation infrastructure, to make their practices and policies greener and more sustainable. Accordingly, environmental consciousness is on rise and has motivated transportation agencies involved in the construction to investigate strategies that reduce the life cycle greenhouse gas (GHG) emissions associated with the construction and rehabilitation of highway infrastructure. The present paper reviews concept of carbon foot printing and assess carbon dioxide emissions and energy consumption for the production of road pavements by means of a literature review.**

Keywords- Carbon foot print, bitumen roads, concrete roads, greenhouse gases

I. INTRODUCTION

The transportation sector represents the development of a region. The demand for infrastructure intensification increases with the region's pursuit of development goals. The roads are basic infrastructures required for the region's economic growth and connectivity. With the increase in economic activities, the dependence of fossil fuel based energy sources and consequent greenhouse gas (GHG) emissions have increased rapidly in recent times. The transport sector in India consumes about 16.9% (36.5 Mt: million tonnes of oil equivalent) of total energy (217 Mt in 2005– 2006). Various energy sources used in this sector are coal, diesel, petroleum (gasoline) and electricity. Road, rail and air are responsible for emission of 80%, 13% and 6% respectively (TEDDY, 2006)**[1].** Vehicular emissions account for about 60% of the GHG's from various activities in India (Patankar, 1991) **[2].**

The challenge of global climate change has motivated 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. Environmental consciousness is on the rise and many transportation officials are striving to make their practices and policies greener or more sustainable. To analyze 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).

A. Carbon Footprint

Carbon footprint is a commonly used term to describe the total amount of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions for which an individual or organization is responsible. It is usually defined as the total amount of CO_2 and other GHGs emitted over the full life cycle of a product or service. It 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) **[3]**. 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_2emissions for various activities.

B. 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**[4]:**

kgCO_2e = (Amount of a gas in kg) * (GWP of the gas)

In line with the definition given above, the carbon footprint of the road sector can be defined as the total amount of CO_2 and other GHGs (direct and indirect) emitted over the full life cycle of a road.

C. 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))**[5].** 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.

II. CARBON FOOTPRINT OF ROADS

Carbon sources or carbon emission sources are formed in the pavement structure within the boundary of the pavement system, including a series of intermediate products and the unit process of collection. Through data acquisition, the degree of influence and the system boundaries can be reasonably identified. Bitumen pavement construction was divided into two parts, namely, Bitumen mixture production and Bitumen mixture construction. Bitumen mixture production includes aggregate stacking, aggregate supply, bitumen heating, aggregate heating, and mixture mixing. The construction of Bitumen mixture was divided into Bitumen mixture transportation, Bitumen mixture paving, and compaction of Bitumen mixture.

In concrete pavements the stages of carbon emission includes the raw materials production, concrete manufactures and concrete pavement construction. The boundary of carbon emission comprises four stages: material manufacture, transportation, construction, and disposal [4]:

$$CE(S) = CE(S1) + CE(S2) + CE(S3) + CE(S4)$$

Where, CE(S1): Carbon emissions at the material manufacture stage; CE(S2): Carbon emissions at the material transportation stage; CE(S3): Carbon emissions at the construction stage; CE(S4): Carbon emissions at the disposal stage.

III. LITERATURE REVIEW

International Road Federation designed a greenhouse gas calculator—Calculator for Harmonized Assessment and Normalization of Greenhouse-gas Emissions for Roads (CHANGER)—for road infrastructure projects. It is compatible with the International Panel on Climate Change (IPCC) guidelines and could be used to monitor and assess greenhouse gas emissions (GHG) generated during the different stages of the road construction process [6, 7].

Huang et al. (2009) developed a spreadsheet-based LCA tool for construction and maintenance of bitumen pavements. The model consists of five worksheets. These are process parameters (e.g., energy in transportation), pavement parameters (e.g., pavement dimensions), unit inventory (i.e., energy production), project inventory (e.g., production process), and characterization results (e.g., global warming) [8] LCA tools for measuring carbon emissions are formalized by the International Organization for Standardization (ISO) 14040 series, particularly the ISO 14040:2006 Principles and Framework [9] and ISO 14044:2006 Requirements and Guidelines [10]. These two together describe the basic concepts and methodologies for LCA studies. For measuring carbon emissions of pavement projects, various practical tools have been developed. For instance, in 1997–1999, Eurobitume conducted an LCI study on paving grade bitumen. A new version in 2011 included polymer-modified binder and bitumen emulsion [11]. The bitumen LCI as a cradle to gate study covers: extraction of crude oil; transport to Europe including pipeline and ship transport; manufacturing of bitumen; and hot storage of the product. It also takes into account the construction of production facilities [11].

In 2011, UK Transport Research Laboratory, in collaboration with the Highways Agency, Mineral Products Association and Refined Bitumen Association, built an bitumen Pavement Embodied Carbon Tool (as PECT) [12]. This UK-based tool is able to produce PAS (Publicly Available Specification) 2050-compliant cradle-to-grave carbon footprint reports for bitumen[13]. The boundary covers: the cradle to gate CO_2e (CO_2 equivalent) of each constituent material and ancillary material; the transport CO_2e from factory gate to plant; CO_2e arising from all forms of energy involved in producing the bitumen at the mixing plant, other than that involved in heating and drying, but including energy for offices on site; and CO_2e arising from the process of heating [12].

Anil Singh et al. (2008)studied trends of greenhouse gas emissions form the road transport sector in India. Emission estimates have revealed that nearly 27 Mt of CO_2 were emitted in 1980, increasing to about 105 Mt in 2000.[14]

Shashwath Sreedhar et al. (2016) developed a spreadsheet computer tool using the Microsoft® Excel platform, designated as "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 carbon footprints of the flexible and rigid pavement systems during the various stages of construction. As observed, there was an insignificant change in the overall emissions in the flexible bitumen 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 (1.37×10^6 for cement concrete versus 2.06×10^3 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 bitumen mixing and compaction. Overall, the emissions for the rigid concrete pavements were found to be greater than the flexible bitumen pavement structures (approximately, a differential of 25% between the two pavement systems).[15]

T.V. Ramachandra et al. (2015)Studies GHG footprint of major cities in India that (Aggregation of Carbon dioxide equivalent emissions of GHG's) of Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad and Ahmedabad are found to be 38.63 million tons, 22.78 million tons, 14.81 million tons, 22.09million tons, 19.79 million tons, 13.73million tonsand 91.24million tons CO_2eq., respectively. The major contributors sectors are transportation sector (contributing 32%, 17.4%, 13.3%, 19.5%, 43.5%, 56.86% and 25%), domestic sector (contributing 30.26%, 37.2%, 42.78%, 39%, 21.6%, 17.05%

and 27.9%) and industrial sector (contributing 7.9%, 7.9%, 17.66%, 20.25%, 12.31%, 11.38% and 22.41%) of the total emissions in Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad and Ahmedabad, respectively. Chennai emits 4.79t of CO_2 equivalent emissions per capita, the highest among all the cities followed by Kolkata which emits 3.29t of CO_2 equivalent emissions per capita. Also Chennai emits the highest CO_2 equivalent emissions per GDP (2.55t CO_2 eq./Lakh Rs.) followed by Greater Bangalore which emits 2.18t CO_2 eq./Lakh Rs.[16]

IV. DISCUSSION AND CONCLUSION

The tools discussed in literature review are employed for the analyses are based on published materials from ISO 14040, Vic Roads, and the Ministry of Transportation for Ontario. In every case, the analyses show clearly that bitumen has a far lower carbon footprint. This means that bitumen pavements are the more sustainable choice. The reduction in carbon emission is possible by generating country specific emission factors for different vehicle categories and improvement in documentation of fuel consumption at segregated levels by fuel types and vehicle types. For the rigid cement concrete 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. 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 bitumen mixing and compaction. Overall, the emissio ns for the rigid concrete pavements were found to be greater than the flexible bitumen pavement structures (approximately, a differential of 25% between the two pavement systems) [15].

REFERENCES

[1] TEDDY, 2006. Teri Energy Data Directory and Yearbook, 2005–06. Tata Energy Research Institute, New Delhi.
[2] Patankar, P., 1991. Urban Transport in India in Distress. Central Institute of Road Transport, Pune, India.
[3] Kyoto Protocol Reference Manual - On Accounting of Emissions and Assigned Amount.United Nations Framework Convention on Climate Change. 2008.
[4] Youliang Huang et al. Measuring Carbon Emissions of Pavement Construction in China, research article MDPI, Basel, Switzerland, (2016),
[5] Carbon Footprinting Management Guide.Carbon Trust., http://www.carbontrust.com/media/44869/j7912_ctv043_carbon_footprinting_aw_interactive.pdf (Accessed on march 18, 2018)
[6] IRF (International Road Federation). Calculator for Harmonised Assessment and Normalisation of Greenhouse gasEmissions for Roads; IRF: Alexandria, VA, USA, 2013.
[7] Huang, Y.; Hakim, B.; Zammataro, S. Measuring the carbon footprint of road construction using CHANGER. Inter. J. Pavement Eng., 14, 590–600. 2009.
[8] Huang, Y.; Bird, R.; Heidrich, O. Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. J. Clean. Prod. 17, 283–296, 2009.
[9] ISO 14040. Environmental Management—Life-Cycle Assessment—Principles and Framework; International Organization for Standardization: Geneva, Switzerland, 2006.
[10] ISO 14044. Environmental Management—Life Cycle Assessment—Requirements and Guidelines; International Organization for Standardization: Geneva, Switzerland, 2006.
[11] Blomberg, T.; Barnes, J.; Bernard, F.; Dewez, P.; Clerc, S.L.; Pfitzmann, M.; Porot, L.; Southern, M.; Taylor, R. Life Cycle Inventory: Bitumen; The European Bitumen Association: Brussels, Belgium, 2011.
[12] Wayman, M.; Schiavi-Mellor, I.; Cordell, B. Protocol for the Calculation of Whole Life Cycle Greenhouse Gas Emissions Generated by Asphalt—Part of the Asphalt Pavement Embodied Carbon Tool (asPECT); IHS Press: Norfolk, VA, USA, 2011.
[13] Huang, Y.; Spray, A.; Parry, T. Sensitivity analysis of methodological choices in road pavement LCA. Int. J. Life Cycle Assess. 18, 93–101, 2012,
[14] Singh, Anil & Gangopadhyay, S & K Nanda, P & Bhattacharya, Sumana & Sharma, Chhemendra & Bhan, C. Trends of greenhouse gas emissions from the road transport sector in India. The Science of the total environment. 390. 124-31, (2008).
[15] S. Sreedhara, P. Jichkarb, and K. Prapoorna Biligiric Investigation of Carbon Footprints of Highway Construction Materials in India, Transportation Research Procedia 17, 291 – 300 (2016)
[16] Ramachandra, TV and Aithal, Bharath H and Sreejith, K, GHG footprint of major cities in India. In: RENEWABLE & SUSTAINABLE ENERGY REVIEWS, 4 . pp. 473-495, (2015)