Creating Innovative Solutions for a Sustainable Future

Life cycle assessment methods to support India’s efforts to decarbonise transport

April 14, 2021
### About the study

<table>
<thead>
<tr>
<th>Title</th>
<th>Reducing Carbon Footprint and Enhancing Climate Resilience of National Highways in India</th>
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</thead>
<tbody>
<tr>
<td>Supported by</td>
<td>Ministry of Road Transport and Highways and the World Bank</td>
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</tbody>
</table>
| Aim | 1. To suggest strategies for reducing carbon footprint of NH network in India  
2. To suggest strategies for enhancing the resilience of NH network to extreme climate change induced events |

INTERLINKED OBJECTIVES

Component I

Carbon Emissions from NH sector

Need for Carbon Emissions Reduction from NH sector

Climate Change impacts and extreme events

Component II

Need for making National Highways Climate Resilient

Increasing climate vulnerabilities of NHs
REDUCTION OF CARBON FOOTPRINT OF NATIONAL HIGHWAYS
OBJECTIVES

• To determine the overall carbon footprint of the NH network

• To suggest low carbon interventions for the highway sector

• To estimate carbon reduction potential of developing ‘good-quality’ highways vis-à-vis ‘poorly-maintained’ highways

• To provide recommendations for mainstreaming of strategies, policies and enabling actions for low carbon NH sector
LCA is a systematic way of evaluating the environmental impacts of products or activities by following a ‘cradle to grave’ approach - it involves identification and quantification of material and energy consumption and emissions which affect the environment at all stages of the entire product of life cycle (ISO 14042).
Estimating Carbon Footprint of NH sector - Approach

Life Cycle Analysis Approach Adopted

Total CO₂ emissions over the full life cycle of NHs considered

- CO₂ Emissions on account of CONSTRUCTION
- CO₂ Emissions on account of MAINTENANCE
- CO₂ Emissions on account of OPERATIONS
Methodology

LCA approach selected to undertake carbon footprinting of NH network

- **Construction & Maintenance phases**
  - Estimation of **project-level CO₂ emissions** (tonnes CO₂ per lane km per year)
  - Extrapolation of **project level** estimates to derive CO₂ emissions from entire NH sector
  - CO₂ emissions estimation during Construction & Maintenance phases for **entire NH**

- **Operations phase**
  - Estimation of transport demand on National Highways (passenger + freight)
  - Estimation of CO₂ emissions from movement of vehicles on NHs
  - CO₂ emission estimation during Operation phase from entire NH

- **NITI Aayog’s IESS Tool (which uses TERI’s Transport Demand, Energy and Emissions estimation model)**

**Total CO₂ emissions from the NH network**
# International and Indian studies on carbon footprint estimates

<table>
<thead>
<tr>
<th>Name of study</th>
<th>Design life of the road considered</th>
<th>Pavement typology</th>
<th>CO₂ emissions/embodied energy during the three phases of highway’s life</th>
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<tbody>
<tr>
<td><strong>International studies</strong></td>
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<tr>
<td>Life Cycle Assessment of Road: A Pilot Study for Inventory Analysis (Stripple, 2001)</td>
<td>40 years</td>
<td>Asphalt pavement</td>
<td>23 TJ/km (Embodied Energy) [Construction, maintenance and operations data combined value was available]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete pavement</td>
<td>27 TJ/km (Embodied Energy) [Construction, maintenance and operations data combined value was available]</td>
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<tr>
<td>Carbon Footprint for HMA and PCC Pavements (Mukherjee, 2011)</td>
<td>15 years</td>
<td>Asphalt pavement</td>
<td>511.27 (MT CO₂Eq./year/lane mile) [Construction, maintenance and operations data combined value was available]</td>
</tr>
<tr>
<td>The Greenhouse Gas Emission from Portland Cement Concrete Pavement Construction in China. (Feng Ma, 2016)</td>
<td>Not indicated in the study/paper</td>
<td>Concrete pavement</td>
<td>2,053.83 (ton CO₂/lane km) X X X</td>
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<tr>
<td><strong>Indian studies</strong></td>
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<tr>
<td>Methodology for Estimating Carbon Footprint of Road Projects: Case Study India (Asian Development Bank, 2010)</td>
<td>22 years</td>
<td>Asphalt pavement [NH (MP/UP): East West Corridor; 4 lane]</td>
<td>24 (ton/lane km/year) 2.8 (ton/lane km/year) 826.7 (ton/lane km/year)</td>
</tr>
<tr>
<td>Life Cycle Analysis of Transport Modes (TERI, 2012)</td>
<td>30 years</td>
<td>Asphalt pavement [Rohtak-Bawal NH-71; 4 lane]</td>
<td>28.7 (ton/lane km/year) X X X</td>
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<tr>
<td></td>
<td></td>
<td>Asphalt pavement [Delhi-Agra NH-2; 6 lane]</td>
<td>X 5.97 (ton/lane km/year) X X X</td>
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Estimating Carbon Footprint of NH sector – Approach (C&M)

LCA approach selected to undertake carbon footprinting of NH network (consonance with International and Indian best practices\(^1\))

**Construction & Maintenance phases**

- Estimation of **project level** CO\(_2\) emissions (tonnes CO\(_2\) per lane km per year)

  *Extrapolation* of project level estimates to derive CO\(_2\) emissions from entire NH sector

  CO\(_2\) emissions during Construction & Maintenance phases **for entire NH**

TERI’s excel-based model developed as part of this study
Phases and processes involved in Calculating CF (C&M)

- Production of materials
- Transport of materials
- Movement of labour
- Construction and maintenance at site
- Construction + Maintenance (annual and periodic)
  - Embodied carbon of materials and fuel; and consumption of energy for transport of materials
  - Direct emission from machinery, movement of labour, materials, etc. during construction and maintenance phases
  - Indirect emission from production of fuels like petrol and diesel

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Selecting representative NH for CF Estimation

Selection of representative highways based on

Geographical and environmental parameters (Terrain, physiography, etc.)

Other highway parameters (Construction materials, Type of work, etc.)

Identifying ongoing/under maintenance projects, which satisfy the above criteria, in consultation with the MoRTH

Exploring the availability of data for construction and maintenance phases from the representative National Highways

Selection of road stretches where data is available with the agencies
Estimating Carbon Footprint of NH sector – Approach (Operations)

Operations phase

Estimation of transport demand on National Highways (passenger + freight)

Estimation of CO$_2$ emissions from movement of vehicles on NHs using NITI Aayog’s IESS Tool

CO$_2$ emissions during Operation phase from entire NH

NITI Aayog’s IESS Tool
(which uses TERI’s Transport Demand, Energy and Emissions estimation model)
Project level estimates – Representative Stretch Locations

- Primary data of 11 National Highways covering 860 km used to estimate CO₂ emissions for construction and maintenance phases

Source: TERI Analysis
CO$_2$ emissions on account of **embodied carbon** in materials is in the range of **72% to 95.4%** of the total construction phase for the sample projects.

Emphasizes the need to use low carbon/local materials.

Stretch-wise emission share of transport of materials, fuel, etc.; on-site energy consumption; and embodied materials on account of construction

(Source: TERI Analysis, 2016)
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**Project level Estimates - Key Findings**

CO₂ emissions on account of movement of materials from source to site of consumption is in the range of 4% to 26% of the total construction phase for the sample projects.

Emphasizes the need to reduce the lead/use of efficient mode of transportation.

Stretch-wise emission share of transport of materials, fuel, etc.; on-site energy consumption; and embodied materials on account of construction (Source: TERI Analysis, 2016)
Project level Estimates - Key Findings

- Number of cycles of periodic maintenance also has a large implication on the resulting emissions from maintenance phase
- Preventive maintenance techniques help in extending the lifetime of road pavements
- Good riding quality leads to higher vehicle efficiencies, lower emissions, and cost savings

Emphasizes the need to maintain good quality road network
CO₂ emissions of entire NH network – C&M phases

Scaling up of project-level emissions

- Use of emission factors per lane km for construction and maintenance for different terrains to arrive at National-level CO₂ emissions
- The two phases account for about 14% of the total CO₂ emissions from the NH sector

NH length to grow from 3.3 lakh lane km in 2016 to 5.7 lakh lane km in 2030

Source: TERI Analysis, 2016
Co$_2$ emissions - Operations phase

NITI Aayog’s IESS model

Traffic on NH (2016)

30% of total pass. km
50% of total tonne km

105 MT CO$_2$e from vehicle operations, which is 41% of total transport sector emissions

Growth trajectory of CO$_2$ emissions from vehicular operations on National Highways

Operations phase accounts for 86% of the total emissions from the 3 phases

Source: TERI Analysis, 2016
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Largest share of vehicular emissions on highways is from HDVs (47% in 2016-17), followed by bus and omnibus, cars, and LCVs

Category-wise CO₂ emissions from vehicular operations on Indian NH network

Source: TERI Analysis, 2016
Total CO$_2$ emissions – NH Sector (2016 & 2030)

- Operations phase is expected to continue to account for the maximum share in CO$_2$ emissions between 2016 and 2030 (i.e. 86%)

**CO$_2$ emissions on account of construction, operation and maintenance of National Highways in India during 2016 and 2030**

- 2016: 123 MT CO$_2$e
  - Construction: 105.1 MT CO$_2$e
  - Maintenance: 2.7 MT CO$_2$e
  - Operations: 15.0 MT CO$_2$e

- 2030: 278 MT CO$_2$e
  - Construction: 247.8 MT CO$_2$e
  - Maintenance: 4.7 MT CO$_2$e
  - Operations: 25.8 MT CO$_2$e

Source: TERI Analysis, 2016
Interventions for emission Reduction (Operations Phase)

- Expedite implementation of fuel efficiency norms
- Fund provision for maintenance of NH network
- Shift to larger trucks
- Move to Electric Drivetrains/alternate fuels

- Improve fuel efficiency levels by 20%
- Can lead to 15% reduction in annual highway emission in 2030
- Adequate budget/fund allocation towards highway maintenance for EPC projects
- Moving freight on larger trucks, with higher capacities
- High engine-weight ratio: Use of engine capacity of >9 litres
- Significant potential to reduce emissions, provided adequate infrastructure is in place
Interventions for emission Reduction (Operations Phase)

Establish stringent regulations for reducing emissions from in-use vehicles

It is recommended that the process of tree plantation under the National Green Highways Mission be expanded to cover the entire NH length

Creation of Carbon Sink through afforestation and reforestation

Establishment of a robust inspection and maintenance (I&M) regime and policy for phasing out/scrapping end of life vehicles (ELVs)

Increase share of public transport

If measures undertaken to retain and improve share to 72%, corresponding reduction in emissions will be 10%
Promote the use of Green Construction Technologies:
- Warm Mix Asphalt
- Cold Mix Asphalt
- Microsurfacing
- Soil stabilisation

Alternate materials:
- Reclaimed Asphalt Pavement (RAP)
  - Geo-Synthetics
  - Plastic Waste
  - Rubber Waste
INTERVENTIONS FOR EMISSION REDUCTION (CONSTRUCTION AND MAINTENANCE PHASE)

Planning stage
- Designing the vertical grade with higher initial speed with vertical grade less than 6%.
- Designing vertical curve higher K-values.
- Alignment selection – Use of LiDAR

Construction stage
- Advanced highway construction practices
  - Use of efficient machinery and equipment
  - Maintenance of machinery/equipment
  - Machinery and equipment with advanced equipment technology and fuels
  - Training of equipment operator
- Slot dozing
- Production of bituminous and concrete mix
- Efficient transportation of construction material (water/rail)

Maintenance stage
- Routine/Periodic Maintenance
- Microsurfacing
Mainstreaming Interventions (construction and maintenance phases)

<table>
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<tr>
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<th>Recommendations</th>
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| Developing National Highway Carbon Estimates for construction and maintenance phases | • The excel-based National Highway model/tool developed by TERI to estimate CO₂ emissions during construction and maintenance phases could be used by the DPR consultants while undertaking project feasibility studies  
  • The DPR consultants will require training                                                                                                           |
| ‘Green Rating System’ for Indian National Highways sector             | • Using TERI’s excel-based NH model, NHAI/MoRTH could develop a compendium of emissions estimated for various NH projects  
  • Based on this, a ‘Green Rating System’ could be initiated, which would help quantify the performance of National Highway projects on a carbon footprint scale.  
  • A pool of experts for evaluating carbon emissions could be housed in MoRTH under an appropriate department/unit proposed in Component II of the study |
| Better data management for estimating carbon footprint of NHs         | • For a number of projects, complete data was not available for the estimation purpose.  
  • A data template has been suggested, which could be used for energy and carbon emission related estimation                                                                                     |
### Mainstreaming Interventions (construction and maintenance phases)

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| Updating/enforcing IRC Guidelines and Codes for construction materials and methods | - There are several materials/methods which are covered under the IRC Guidelines/Rules but are not deployed or used due to various reasons  
- For these materials, more awareness or more demonstration projects need to be undertaken. |
| Construction materials/ methods not under IRC Guidelines/Codes         | - More R&D and pilots projects need to be undertaken regarding such products with the help of PWDs and research organizations like CRRI  
- Adding these materials in IRC guidelines will give an option to the contractors to procure locally available materials and reduce the lead for procuring conventional materials from far off places |
| Constitution of R&D Innovation Support Fund                            | - R&D innovation support fund should be constituted to encourage/promote the use of green materials/technologies.  
- Some part of the incremental cost on account of using alternate/green materials could be borne by the implementing authority. |
## Mainstreaming Interventions (construction and maintenance phases)

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| Other policy and DPR related suggestions | • Government should ensure that certain percentage of National Highways should be developed using green materials or technologies  
• The additional cost burden should be shared, where the government/authority could use the R&D Innovation Support Fund to promote green materials/technologies  
• In the bidding document, competitive advantage should be given to the bidders/contractors who are keen to use green material/technology while constructing National Highways  
• To encourage the use of green/alternate materials in National Highways, life cycle analysis should be made mandatory for every project. In addition, the total life cycle cost and emissions of projects should be compared under two scenarios:  
  - Scenario 1: When conventional materials/technologies are used  
  - Scenario 2: When green/alternate materials are used |
TERI study on urban transport LCA

A life cycle analysis of urban public transport systems in Indian cities

- BRTS
- MRTS

Selected TERI Reports

- Faster adoption of electric 2W in India: A perspective of consumers and industry
- Switching to a Sustainable Auto-rickshaws System
- Integrating electric buses in public transport: Kolkata's success story
- Roadmap for Electrification of Urban Freight in India
- Benefits of Cycling in India
- Impact of COVID-19 on urban mobility in India: Evidence from a perception study
- Making Mission Possible: Delivering a Net-Zero Economy
- Increasing the Rail Share in Freight Transport in India
- Comparison of Decarbonisation Strategies for India’s Land Transport Sector: An Inter Model Assessment
- Reduction of Carbon Footprint in Highways Sector
Thank you

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