Ministry of Road Transport and Highways

World Bank Technical Assistance Program

Reducing Carbon Footprint and Enhancing Climate Resilience of National Highways in India

Component I: Reducing Carbon Footprint of National Highways

The Energy and Resources Institute

Ministry of Road Transport and Highways
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Abbreviations and Acronyms

BAU	Business as usual
BEE	Bureau of Energy Efficiency
C&D	Construction and Demolition
CF	Carbon footprint
CO2	Carbon dioxide
ELVs	End-of-life vehicles
EIO	Environmental Input-Output
GHG	Greenhouse gas
GoI	Government of India
HDV	Heavy duty vehicle
HMA	Hot-mix asphalt
IESS	India Energy Security Scenario
IHMCL	Indian Highways Management Company Limited
IRC	Indian Roads Congress
LCA	Life Cycle Analysis
LCV	Light commercial vehicle
MoEFCC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
NDC	Nationally Determined Contributions
NHs	National Highways
NHAI	National Highways Authority of India
NHDP	National Highways Development Programme
OBDS	On-board diagnostic system
pkm	Passenger km
PUC	Pollution under control
PWD	Public Works Department
R&D	Research and Development
RAP	Recycled asphalt pavement
tkm	Tonne km
UNFCCC	United Nations Framework Convention on Climate Change
WMA	Warm-mix asphalt

Glossary of Terms

Climate Change

"A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use." (IPCC, 2012)

Carbon Footprint

"A methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)." (Carbon Trust, 2007)

Life Cycle Analysis

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle." (ISO 2009)

Mainstreaming

"Mainstreaming can be defined as the "integration of climate change related policies and measures into developmental planning process and decision-making." (Eriksen S E H, 2005)

Mitigation

"The lessening or minimizing of the adverse impacts of a hazardous event." (UNISDR, 2017)

Introduction to the Study

Road transport, especially highways,[1] plays a pivotal role in the development of a country. The development of highways fosters movement of passenger and freight across the country leading to increased national productivity and socio-economic growth. Though constituting only 2% (103,933 km, as on March 31, 2017) of the total road length in the country, National Highways form the backbone of the road transport sector, moving almost 40% of the total road traffic (MoRTH, 2015-16).

India has long realized the importance of highways and has been giving the necessary impetus for its development in the country. The Government of India (GoI) has launched various programmes to build new highways and to improve and upgrade the existing highways in order to meet the ever-growing transport demand. The government plans to build about 50,000 km of National Highways in the next five years (Lok Sabha, 2016). The construction and subsequent use of highways, however, has implications in terms of increased use of energy and generation of CO_2 emissions.

Amidst growing concerns of energy security and climate change, there is a realization that the transport sector, especially the road sector should lower its dependence on fossil energy and reduce its carbon footprint. Overall, India's transport sector contributed about 14% of total energy-related CO_2 emissions in 2010, of which, road transport is estimated to contribute about 88% (BUR, 2015).

Given the increasing length/capacity of the highway network, and the increasing volumes of traffic on highways, CO_2 emissions from highways (on account of construction, maintenance, and operation activities) are expected to continue increasing in a business-as-usual scenario, if interventions are not made to mitigate the same. With India's Nationally Determined Contributions (NDC) commitment[2] to reduce carbon emissions, it has become imperative that the country's highway sector be made low carbon.

Additionally, the sector is also required to build resilience to climate change impacts in order to reduce risks and protect the highway infrastructure from impacts of climate change, such as sea-level rise, extreme precipitation, rising temperature, and climate-induced extreme events. This requires an understanding of carbon emissions emitted from the highway sector in India and an assessment of vulnerability of National Highways to extreme weather events induced by climate change.

Both the components – (a) carbon footprint exercise for the National Highway network of India and recommended interventions to reduce the same and

[1] In the context of this study, 'highways' specifically refer to the National Highways

[2] http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf; last accessed on June 14, 2017

(b) developing vulnerability assessment methodology and recommended interventions for enhancing the climate resilience of the NH network – are interlinked, as carbon emissions, in general from all anthropogenic activities have been cited as a key reason for climate change and the associated extreme events (IPCC, 2012) (IPCC, 2014).

While studies have been undertaken to understand project-level carbon footprint of specific NH stretches,[3] there are no studies to our knowledge that have been undertaken to estimate the carbon footprint of the entire NH sector in India. Also, there are no known studies that have aimed at understanding the climate vulnerability of the National Highways in the country.

The Ministry of Road Transport and Highways (MoRTH), Government of India, supported by the World Bank, therefore, has commissioned this particular study to The Energy and Resources Institute (TERI), New Delhi to estimate the carbon emissions from National Highways sector (emissions from construction, operation, and maintenance activities) and to suggest methodologies and interventions to assess and reduce the vulnerability of the highway sector to climate change-induced extreme weather events. The study is divided into the following two components:

- Component I of the study focuses on estimating and suggesting measures to reduce the carbon footprint of the NH sector
- Component II of the study focuses on suggesting a methodology for assessing and enhancing climate resilience of the NH sector

The report is divided into two parts and states the work carried out under the two components separately.

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[3] a. https://www.adb.org/publications/methodology-estimating-carbon-footprint-road-projects-case-study-india; last accessed in June 2017

b. http://tripp.iitd.ernet.in/publications/NTDPC/study%20reports/LCA_Final%20Report%20Vol%20I.pdf; last accessed in June 2017

c. http://tripp.iitd.ernet.in/publications/NTDPC/study%20reports/LCA_Final%20Report%20Vol%20II.pdf; last accessed in June 2017

d. https://www.omicsgroup.org/journals/estimation-of-carbon-footprints-of-bituminous-road-construction-process-2165-784X-1000198.pdf; last accessed in June 2017

e. http://www.sciencedirect.com/science/article/pii/S2352146516307104?via%3Dihub; last accessed in June 2017

COMPONENT I

Reducing Carbon Footprint of National Highways in India

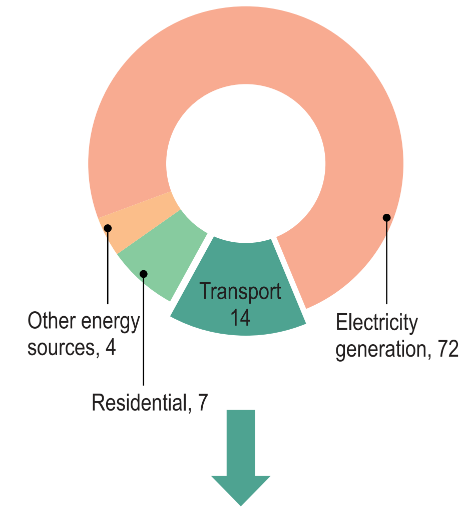
1 Introduction

1
Introduction

1.1 Background and need for the study

The transport sector is one of the leading contributors to India's greenhouse gas (GHG)[1] emissions. Further, the share of global energy-related GHG emissions from the transport sector are projected to grow at a rapid pace from 22% in 2009 to 80% by 2050 (IPCC Working Group III, Fifth Assessment Report, 2014). As per India's latest Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change (UNFCCC),[2] the transport sector was responsible for 14% of India's total energy-related CO_2 emissions (BUR, 2015). It is the second-largest contributor to energy-related CO_2 emissions after the electricity generation sector (Figure 1). Within transport, the share of road transport in CO_2 emissions stood at 88% in 2010.

The road transport sector is primarily dependent upon petroleum products and is the largest consumer of liquid hydrocarbons in the country. It is estimated that India's road transport sector accounted for 66% of the total diesel and 99.6% of the total petrol consumption during 2012 (PPAC, 2012-13). The dependence of the road sector on fossil fuels is expected to continue increasing leading to high levels of CO_2 emissions in the business-as-usual scenario. A large portion of CO_2 emission from the road transport sector is being



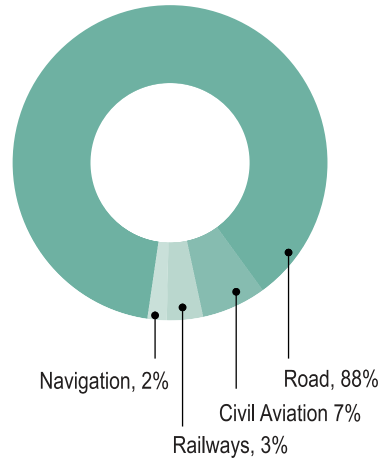


Figure 1: First pie: India's energy-related CO_2 emissions in 2010: Share of different sectors Second pie: Share of different transport modes in total CO_2 emissions from the transport sector

(Source: BUR, 2015)

[1] Greenhouse gases (GHGs) include carbon dioxide (CO_2), methane (CH_4), and Nitrous oxide (N_2O)

[2] http://www.moef.gov.in/sites/default/files/indbur1.pdf

emitted on account of construction and maintenance of and traffic movement on National Highways (NHs). NHs in India carry the bulk of the long-distance road traffic and are witnessing a rapid growth in both network capacity and traffic volumes.

With the global focus shifting to low-carbon transport, the highway sector offers a significant opportunity of reducing the carbon footprint of road transport. To establish a low-carbon highway sector in the country, it is, therefore, important to estimate and understand the carbon footprint/carbon emissions profile of the existing highway sector in India to arrive at a baseline, which can then help to identify areas of low-carbon interventions throughout the life cycle of highways. Carbon footprint, which is defined as the total amount of greenhouse gases produced to support human activities, is expressed in equivalent tons of carbon dioxide (CO_2) (Laurence A Wright, 2011). It is usually estimated on a life cycle basis, as a life cycle approach helps in understanding the 'total' CO_2 impacts of a sector/product/service.

1.1.1 National Highways: The focus of this study

The NHs carry the major bulk of traffic, both passenger as well as freight traffic. NHs account for about 2% of the total road network in India and carry about 40% of the total road traffic (Figure 2) (MoRTH, 2016). With a total length of about 103,900 km in 2017,[3] the NH network is referred to as the backbone of the Indian road transport system and is, therefore, prioritized for investments and improvements.

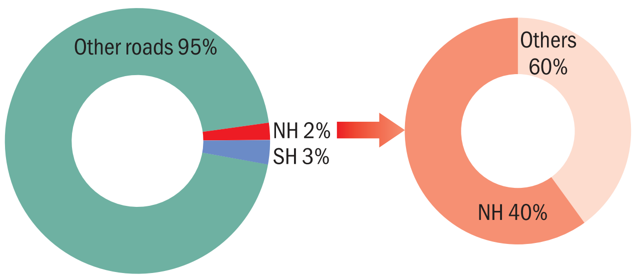


Figure 2: Share of national highways in the total road network and total traffic (MoRTH, 2016)

Note: Other roads include district roads and rural roads

Growth in NH network

The NH length in India has almost doubled since 2001. This growth has largely happened on account of new construction, expansion work as well as conversion of a number of State Highways into National Highways by the MoRTH. During the last 3–4 years, there has been a significant jump in the NH length which could be, in part, explained by the government's decision to declare State Highways as National Highways (Figure 3). According to the MoRTH, about 18,000 km of State Highways have been converted into National Highways between April 2013 and March 2016.[4]

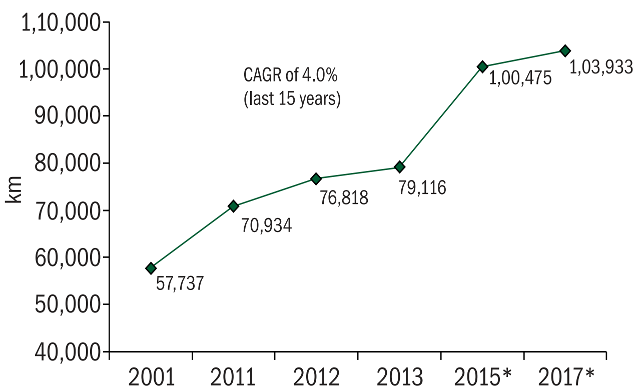


Figure 3: Growth of National Highway network in the last 16 years (MoRTH, 2015–16 and Annual Report 2016–17)

Note: * As of December, 2015; ** As of March 2017

As stated earlier, National Highways carry the bulk of long-distance road traffic. From the perspective of low-carbon growth which requires significant reduction in CO_2 emissions from road transport, NHs, therefore, become an important intervention area. Given the increasing demand from passenger and road transport segments and the subsequent development works in the NH sector, there is an urgent need to identify all potential carbon mitigation measures in the NH sector where carbon reductions are possible. This requires carrying out an inventory of carbon emissions being generated by the NHs sector on account of various activities, such as construction/upgradation work, traffic movement, and maintenance work. Such a carbon footprinting exercise for highways can clearly indicate the intervention areas where reduction in carbon emissions is possible/required. This study focuses on carrying out this carbon footprinting exercise for the NHs network in India with an aim to identify carbon mitigation measures for the sector. The study takes a holistic view of the NH sector and focuses on all carbon emission sources, such as

[3] MoRTH Annual Report 2016-17 (http://morth.nic.in/showfile.asp?lid=2631)

[4] http://164.100.47.190/loksabhaquestions/annex/8/AU864.pdf

construction, maintenance, vehicular emissions, etc. rather than limiting the scope of carbon inventory to just tail-pipe emissions.

Construction-related carbon emissions: The length of the NHs is all set to increase at a fast pace (Box 1). This implies huge construction works in the sector, which has implications for low-carbon growth, as construction of highways generates CO_2 emissions from activities, such as movement of materials and manpower, fuel consumption at site, material consumption (embodied carbon of materials), etc. It is estimated that every lane km of NH constructed generates CO_2 emissions to the tune of 24–30 tonne per year (Annexure 1 provides estimates from the past studies for CO_2 emissions from different phases of NHs [construction, operation, and maintenance phases], both international and national studies).[5] There is a huge scope to reduce these emissions by deploying low-carbon measures in the construction of NHs.

BOX 1: PLANNED EXPANSION OF THE NHs (2015–20)

The central government is planning a significant expansion of NHs network in the country. This will be done mainly through the development/expansion of NHs under programs, such as the National Highways Development Programme (NHDP), Char Dham Connectivity, District Connectivity Scheme, Special Accelerated Road Development Programme-North East (SARDP-NE), etc. (Figure 4). About 50,000 km of NHs will be constructed/upgraded under these programmes in the next five years. The upgradation and widening of NHs, specifically, is expected to pick up pace. Currently, of the total NH network, only about 22% is four-lane or more, while a majority of the highways (47%) is two-laned (MoRTH, 2016). The remaining, which still comprise a large portion on the highways (32%), have a single or intermediate lanes marked by poor drivability conditions[6] (Table1).

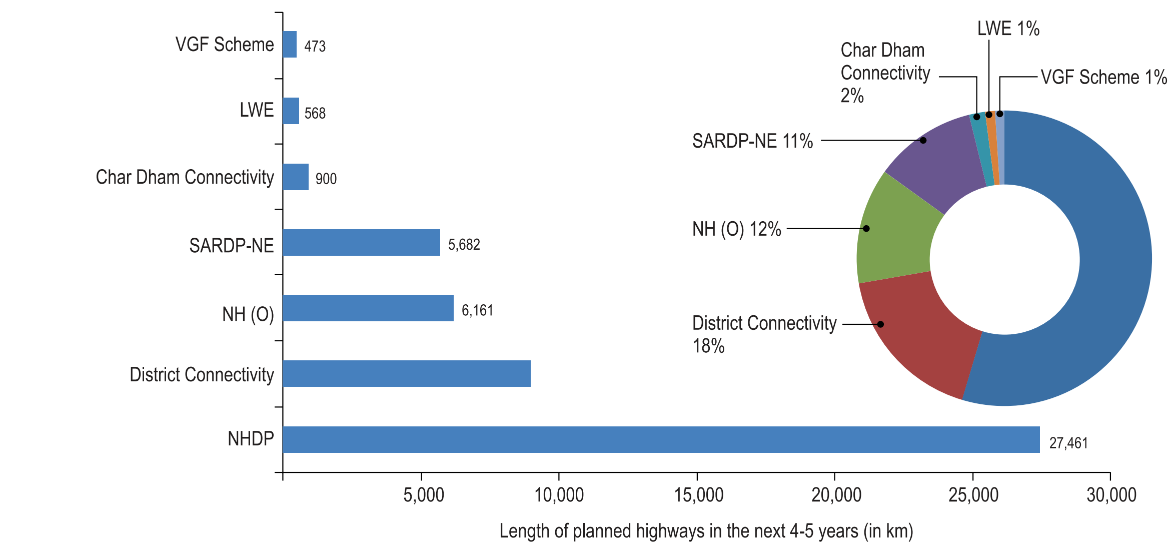


Figure 4: Programme-wise length of NHs to be taken up for construction till 2019–20

Source: Lok Sabha, 2016

Table 1: Lane-wise length of NHs in India in km (as on March, 2015)

Lane	Length in km (share in total %)
Less than 2 lane	31,089 (32%)
2 lane	45,701 (47%)
4 lane and above	21,201 (22%)
Total	**97,991 (100%)**

Source: Basic Road Statistics, 2014–15

[5] Construction work includes expansion of National Highways from two lane to four lane or four lane to six lane, and so on (CO_2 emission estimates are for NHs with asphalt pavement).

[6] http://morth.nic.in/showfile.asp?lid=1762

Maintenance-related carbon emissions: The demand for maintenance of NHs is rapidly increasing on account of the government's effort to provide quality highway infrastructure. As per estimates, carbon emissions to the tune of 2.8–6 tonnes CO_2 per lane km per year are generated on account of both routine and periodic maintenance-related work on highways (Annexure 1), largely occurring because of the use of materials and on-site energy consumption. Maintenance-related emissions can also be reduced by adopting low-carbon materials and maintenance practices.

Emissions during operations: The operations phase, involving movement of vehicles on the highways, account for the highest share of carbon emissions. According to estimates, about 90–5% of the total carbon emissions in a highway's life occur on account of the operations phase (Asian Development Bank, 2010). There is a huge scope for reducing the carbon footprint during the operations phase through interventions, such as improving per tonne km/per passenger km efficiency of road transport, using low-carbon fuels, such as electricity, methanol, CNG, and bio-diesel, etc.

1.2 Objectives of the study

The first component of the study, that is, the component focussing on carbon footprint (CF) of the NHs sector has four broad objectives. These are:

- **Objective 1:** Determining the overall carbon footprint of the NH network
- **Objective 2:** Identifying and comprehensively listing engineering and non-engineering low-carbon interventions for the highway sector (provide the carbon reduction potential and cost estimate for these interventions wherever available)[7]
- **Objective 3:** Estimating the carbon reduction potential of developing 'good-quality' highways as compared to 'poorly maintained highways
- **Objective 4:** Recommending strategies, policies, and enabling actions to enable a low-carbon highway sector in the country

1.3 Tasks and methodology

The main purpose of this study is to provide suggestions for mainstreaming strategies that can enable actions for the development of low-carbon highways sector in the country. Four main tasks were carried under the study to achieve this objective; these have been mentioned in Table 2.

Table 2: Tasks involved under the CF component of the study for NHs

Tasks		Sub-tasks	Steps Involved
Task 1	Carbon footprint (CF) estimation	» Undertaking literature review of accepted CF approaches » Collecting CF estimates for highways from literature » Developing CF estimation methodology » Estimating CFs of typical NH projects/representative highways and extrapolating the project/stretch-level estimates to derive the construction and maintenance activities related CF of total NH sector » Estimating CF of NH operation (vehicular movement on NHs) from TERI's energy and emissions model	» Study approaches used to estimate carbon footprint of highways for the construction, operation, and maintenance phases » Document, from the past studies, the carbon estimates for specific NH stretches in India » Estimate carbon footprint of typical representative NH projects and use it to determine the overall carbon footprint of the NH sector for construction and maintenance activities » Estimate operations/vehicular emission from the NH sector from TERI's energy and emissions model

[7] The final report lists and discusses all possible carbon-reduction interventions collected from literature review and from discussions with stakeholders. Wherever available, their costs and/or CO_2 reduction potential have been indicated (as collected from literature and/or from discussions with sector experts).

Tasks		Sub-tasks	Steps Involved
Task 2	Carbon reduction, interventions, and related costs	» Identifying interventions to reduce the carbon footprint of the NH sector and understanding the cost and carbon-reduction potential of these interventions from literature, if available	
Task 3	Carbon reduction potential: Good- vs poor-quality highways	» Estimating the carbon-reduction potential of maintaining NHs and the associated costs	» Estimate the carbon-reduction potential on account of good maintenance of highways and the related costs
Task 4	Strategies/policies for mainstreaming carbon reduction	» Review of international best practices » Suggesting national-level guidelines for low-carbon growth of the highways sector	» Suggest policy recommendations to incorporate low-carbon interventions in the fabric of National Highways management in India

This report outlines the work and final outcomes of all the four tasks stated above. Chapters 2 and 3 focus on Task 1, that is, reviewing CF approaches, development of CF methodology, and an estimation of CF for the country's NH sector. Chapter 4 focuses on Task 2, that is, a detailed study and discussion on low-carbon interventions that are possible in the NH sector, as well as Task 4, which charts out strategies on how to mainstream the interventions into policy actions. Chapter 5 focuses on the carbon-reduction potential on account of good maintenance of a National Highway.

1.4 Data and information sources

The study is based on a mix of primary and secondary sources of information. Primary data is collected from construction and maintenance sites, including NHAI and Public Works Department (PWD) site offices. Primary data collection involved a number of site visits and meeting the engineers at the project locations. Also, data from the MoRTH and NHAI, which are not in the public domain, were sourced for the purpose of analysis. Table 3 provides the list of sources referred to for the first component of the study.

Table 3: List of data/information sources for the first component of the study

Topic	Key Sources
For background information related to aspects, such as carbon emissions from the sector, information on the NH sector	First Biennial Update Report (BUR), 2015 - Ministry of Environment, Forest and Climate Change; United Nations Framework Convention on Climate Change; Life cycle analysis of transport modes (TERI 2012); MoRTH (Annual Reports, Yearbooks and Basic Road Statistics; Terrain-wise length of National Highways from the Transport Research Wing of MoRTH)
To develop CF methodologies, International and Indian studies were referred	International: Håkan Stripple (2001); Ulla-Maija Mroueh, et al. (2001); Graham J. Treloar, et al. (2004); Chabane Mazri, et al. (2004); Harpa Birgisdóttir (2005); Nicholas Santero, et al. (2010); Darrel Cass and Amlan Mukherjee (2011); Mukherjee, 2011; Feng Ma (2016) India: ADB (2010); TERI (2012); Siksha Swaroopa Kar, et al. (2015)
For CF estimation for the NH sector in India, primary data was collected from NH construction and maintenance sites	NHAI and PWD site offices from where data has been collected: Dehradun and Rudraprayag, Uttarakhand; Lucknow, Raebareli, Etawah, and Orai, Uttar Pradesh; Jodhpur, Rajasthan; Bhubaneshwar, Odisha; Patna, Bihar; and Pune, Maharashtra. Primary data from representative NH projects (listed in the report) were collected for the construction, maintenance, and operations phases based on survey questionnaire formats given in Annexure 3. The responses from the project sites have been submitted to the MoRTH as part of this report. (Annexure 5 gives a list of contacts from whom primary data was collected)

Topic	Key Sources
Data which are not in the public domain were collected from the MoRTH and NHAI	MoRTH: Terrain-wise length of NHs in key states (Annexure 6) NHAI: CAD format map of the NH network (Annexure 7)
For carbon reduction interventions, both international and national sources were referred to	International: D'Angelo et al., 2001; Makusa, 2012; Ning Lee, 2011; Burt Andreen et al., 2011; Matthias Stucki et al., 2011; Prof. Newman et al., 2012; Jorge Sousa et al, 2016; KO, 2011; Wangari, 2011; Stewart, 2003; ICF International, 2010; Stotko, 2011; Parkman et al., 2012; Asian Development Bank, 2010; Boriboonsomsin and Barth 2009; AASHTOW, 2012; Dam, 2014; Deere, John, 2005; NRMCA, 2014; NRMCA, 2008; World Bank, 2010; Nicholas Santero et al., 2013; John Bullough, 2009; Texas Department of Transportation, 2008–2009; Frank Gallivan, 2010; Nicholas Santero, A. L., 2013; Biron, 2014; Thomas, 2009; Federal Highway Administration, 2011; ALAO, 2011; Sherwood, 1993 National: Siksha Kar et al., 2015; Park and Rakha 2006; Rajiv Kumar and Satish Chandra, 2016; Dr P K Jain, 2011; Dr N K S Pundhir, 2011; Pundhir, 2011; Rajesh S. Gujar, 2013; S Sridevi, 2016; Ujjwal J Solanki et al., 2009; Javed, 1992; M S Verma, 2014; G Venkatappa Rao et al., 2013; Parth H Sadadiwala and Prof. Purvi P Patel, 2015; Rajiv Goel and Ashutosh Trivedi, 2015; CEG Justo and A Veeraragavan, 2002; Nanda and Reddy, 2011; Rema Devi et al., 2003; Akhtar, 2011; Jigisha, 2011; Tushar, et al., 2012; B G Buddhdev, 2014; Havanagi et al. 2006, 2008 and 2009; Das et al. 1993; MoRTH, 2001, 2015–16, 2016–17; IS 15462: 2004; Anwar, 2014; Gurumoorthy, 2014; Danh, 2015; K R Manjunath et al., 2012 IRC:SP-100, 2014; IRC SP-37-2012; IRC:SP:101, 2014; IRC-120:2015; IRC:SP 98-2013; IS 15462:2004; IRC: 82-1982; IRC: SP-58 2001; IRC SP 53, 2010; IRC SP: 72: 2007; IRC 113: 2013

2 Estimation of Carbon Footprint: Approach

2
Estimation of Carbon Footprint: Approach

2.1 Carbon footprint: Concept and estimation approaches

To meet one of the primary objectives of this study, that is, to estimate the carbon footprint (CF) of the entire NH sector of India, it was necessary to understand the concept of CF and approaches used to estimate CF, especially CF of the highways/ road infrastructure.

BOX 2: DEFINITIONS OF CF

1. '[the] total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product' (POST, 2006).
2. 'A methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)' (Carbon Trust, 2007).
3. 'Measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product' (Wiedmann, 2008).
4. '[The] total amount of greenhouse gasses produced to support human activities, and is expressed in equivalent tons of CO_2' (Laurence A Wright, 2011).

CF can be estimated using various methods, such as process-based Life Cycle Analysis (LCA), Environmental Input-Output (EIO), and Hybrid IO-LCA models. The choice of a method depends on the strengths and weaknesses of one method over the others and criteria, such as data requirements, source data uncertainty, upstream and downstream system boundary considerations, time, etc. (Eskinder Demisse Gemechu, 2009).

- **EIO model** uses a top-down approach to account for resource flows and environmental impacts based on input-output tables. Under this, generic data at the national level is used to calculate GHG emissions at the industry level based on the emission intensity of the respective industries. This method is used to model CF at the industrial level and helps to provide a holistic view of economic interdependence of industries, but lacks process specificity.
- **LCA,** on the other hand, is process-based and uses a bottom-up approach or cradle-to-grave approach. LCA is defined as '[a] compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle' (ISO 2009). Under this, GHG emissions are calculated based on the energy used throughout the life cycle of the product, including the production, consumption, and disposal stages. The limitation of this method is that it does not cover all upstream processes in greater detail (Eskinder Demisse Gemechu, 2009).
- The **Hybrid IO-LCA** (Suh and Huppes, 2005) links LCA and EIO approaches through various types of models, such as tiered hybrid, input-output based LCA, and integrated hybrid models.

For this study, the LCA method has been adopted to estimate the CF of the India's NH network. The LCA method is the most widely used method to assess environmental implications of products/ services and product carbon footprinting (Gemechu Eskinder Demisse , 2009) (Guniee, 2002) (ISO, 2006). There are various reasons for the selection of the LCA approach to undertake carbon footprinting exercise under this study. These include:

- LCA is product-/service-specific and is claimed to be the best approach to calculate the emission intensities of products and services even though it is data- and time-intensive (Eskinder Demisse Gemechu, 2009).
- It systematically records and analyses the carbon emissions and carries out an integrated assessment throughout the entire life cycle of a product or service.
- Application of the LCA method has also been widely accepted across the world to estimate the CF of infrastructure sectors, especially roads. (Refer to the next section for the list of a few international studies that have used the LCA method).
- An end-to-end analysis of product/service is carried out considering all raw materials, transportation, production processes, and usage and disposal of the product.

CF at a product level is a special application of the LCA methodology that specifically focuses on GHG emissions. CF is defined as 'the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product'.[1] It is usually expressed as grams of CO_2 equivalent (gCO_2eq), which accounts for the different global warming effects of other GHGs. Emissions into the environment during the course of extraction and consumption of resources, production/ manufacture of materials, direct emissions during consumption/use, and at the products' end-of-life (collection/sorting, reuse, recycling, waste disposal) are all considered in CF estimation (Rebitzer G, 2004).

2.2 Methodology for estimating project-level/stretch-wise life cycle CO_2 emissions

2.2.1 Review of methodologies used to estimate the CF of highways/roads

To estimate the life cycle CO_2 emissions/CF of the entire NH sector of India, a comprehensive bottom-up methodology was developed after an extensive review of methodologies used to estimate CF of highways/ roads. Some of the key international and Indian studies that were reviewed are summarized in Table 4. A detailed discussion on studies related to LCA in the Indian scenario is given in Annexure 2.

Table 4: Summary of CF estimation methodologies for highways/roads developed/used in other studies (international and Indian studies)

Study	Author/s and Year of Study	LCA Approach
International studies		
Life cycle assessment of roads: A pilot study for inventory analysis	Håkan Stripple (2001)	The study covers all the phases of a road's life cycle, that is, construction, maintenance, and operations (except emissions from traffic). It includes emissions from sourcing/ production of raw materials to consumption, and recycling of materials
Life cycle assessment of road construction	Ulla-Maija Mroueh, et al. (2001)	The study assesses the life cycle impact procedures for the comparison and evaluation of alternative road and earth constructions
Hybrid Life Cycle Inventory for Road Construction and Use	Graham J. Treloar, et al. (2004)	The Hybrid LCA approach is used to estimate the environmental impact not only during the construction phase but also during the operations phase, including the manufacture, use, and maintenance of vehicles using the road
Life Cycle Analysis and Decision Aiding: An example for roads evaluation	Chabane Mazri, et al. (2004)	The LCA study focuses on environmental impact during the three phases, namely, deconstruction, material sourcing, and construction

[1] http://wgbis.ces.iisc.ernet.in/energy/paper/science-of-carbon/footprint.html; last accessed on September 1, 2017

Study	Author/s and Year of Study	LCA Approach
Life cycle assessment model for road construction and use of residues from waste incineration	Harpa Birgisdóttir (2005)	The LCA study evaluates the environmental impact of using waste materials as well as compares the impact of disposing wastes at landfill sites and using it for road construction
Life cycle assessment of pavements: A critical review of existing literature and research	Nicholas Santero, et al. (2010)	The study critically analyses past LCA of pavements. It focuses on presenting various methods of LCA implementation, along with describing the different types of LCA applied in each research. The study does an exhaustive LCA analysis of each pavement
GHG calculation for highway construction using a hybrid life cycle assessment approach	Darrel Cass and Amlan Mukherjee (2011)	The study includes material acquisition, manufacturing, rehabilitation activities during the construction phase of the pavement
The Greenhouse Gas Emission from Portland Cement Concrete Pavement Construction in China	Feng Ma (2016)	The study involves estimating carbon emissions using the life cycle inventory method for roads constructed using Portland cement. Emissions estimation is limited to the construction phase only and does not include the maintenance and operation phases
GHG Emissions Mitigation in Road Construction and Rehabilitation	(World Bank, 2011)	The study analyses GHG emissions from the construction and rehabilitation of road projects in the South East Asian countries (China, Indonesia, and Vietnam) with a focus on identifying areas to minimize GHG emissions and maximize energy efficiency.
India studies		
Methodology for Estimating Carbon Footprint of Road Projects: Case Study India	ADB (2010)	The study estimates direct and indirect CO_2 emissions under the three phases—road construction, road operations, and road maintenance
Life Cycle Analysis of Transport Modes	TERI (2012)	The study uses the LCA methodology to estimate life cycle energy consumption and CO_2 emissions values for the different modes of transport including highways/roads
Estimation of Carbon Footprints of Bituminous Road Construction Process	Siksha Swaroopa Kar, et al. (2015)	The study calculates the CO_2 emissions released during warm-mix asphalt and cold-mix asphalt methods of road construction
Source: Compiled by TERI		

As can be observed from Table 4, studies that measure carbon footprint/life cycle CO_2 emissions of roads/highways in India are limited. The two existing Indian studies, **'Life Cycle Analysis of Transport Modes' (2012)**[2] and **'Methodology for Estimating Carbon Footprint of Road Projects, Case study: India' (2010)**[3]**,** lay a comprehensive framework for estimating CF from the full life cycle of the three phases of highways/roads, that is, construction, operations, and maintenance. The LCA framework drawn up in TERI (2012) is in line with the ISO 14000 framework for

[2] The study was carried out by TERI for the National Transport Development Policy Committee, Government of India, and focused on measuring the CF of transport infrastructure projects, including highway projects.

[3] The study carried out by the Asian Development Bank involved TERI expert (Ms Akshima T Ghate). The study focused on suggesting CF methodology for road projects (including highway projects) in India; the methodology was used to measure the CF of highways and other road projects in India.

carrying out LCA studies and takes into account the international best practices for carrying out LCA of road infrastructure. For this study, TERI has defined CF of highways as the total amount of CO_2 emitted over the full life cycle of a highway. The main activities that result in carbon emissions during the life cycle of a highway that are considered in TERI (2012) LCA methodology are:

- Embodied carbon of construction materials used in construction and maintenance activities
- Emissions accruing from the mobilization of manpower and machinery for construction and maintenance activities
- Carbon emissions from the use of fossil fuels for operating machineries for various construction/ maintenance activities on-site
- Carbon emissions from the use of fossil fuels for the operation of vehicles (cars, jeeps, trucks, tractor trailers, etc.) for movement of material, machinery, and manpower on-site and external trips
- Energy usage by site offices—carbon emissions on account of electricity used in site offices—during the construction and maintenance phases
- Carbon emissions arising from vehicles on the highway during the operations stage

Figure 5 summarizes the scope of CF methodology adopted in TERI (2012)

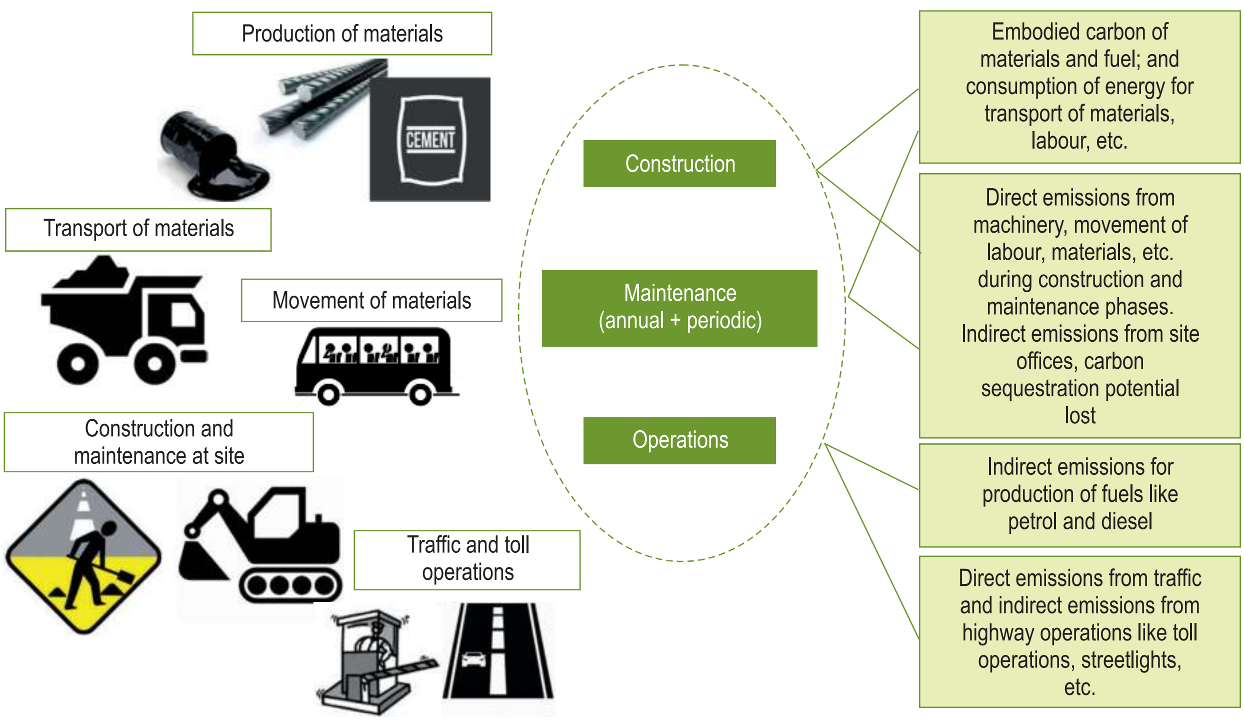


Figure 5: Phases and processes involved while calculating the CF of representative highways in TERI (2012)

2.2.2 Project-level/stretch-wise CF methodology developed/adopted for this study

The methodology adopted in TERI (2012) was found to be a comprehensive LCA approach for estimating CO_2 emissions for highways (project-level/stretch-wise CO_2 estimates). A key strength of this methodology is that it has been developed using international best practices, but while taking into account the Indian scenario of construction and maintenance practices and, more importantly, considers the data availability in the Indian context. This methodology was, therefore, adopted for this study for estimating CO_2 emissions of selected/typical highway stretches. Certain modifications/improvements were carried out to further improve and strengthen this methodology; the key modifications/improvements carried out in the methodology are listed below:

- Addition of construction materials considered in the construction/maintenance analysis

- Update and refinement of embodied energy and CO_2 emission factors of materials and fuels
- Loss of carbon sequestration potential due to the removal of vegetation for the construction/ maintenance of highway is not considered as it is assumed that with the new 'Green Highways Mission' launched by the MoRTH, compensatory vegetation will be planted to make up for the potential loss in carbon sequestration capacities.
- For the operations stage, only direct energy consumption and CO_2 emissions occurring on account of use of fuel in vehicles is considered; embodied CO_2 of vehicles is not considered.

The carbon sources included/excluded in the adopted CF methodology are listed in Table 5. This CF methodology has been used to estimate project-level/ stretch-wise CO_2 emissions.

Table 5: Scope of LCA/CF framework for estimating project-level/stretch-wise CO_2 emissions

Carbon Sources	Included	Remarks/Source
Construction Phase		
Production of construction materials		
Embodied energy and CO_2 of construction materials	Y	India-specific coefficients from AEI (2009) International values from Hammond and Jones (2008)
Indirect energy consumption and CO_2: Energy consumed for constructing buildings, manufacturing machinery, etc. used for the production of materials	N	*Rationale for not including*: Capital assets common infrastructure used for producing construction materials for several projects; embodied energy cannot be included in one project
Transportation of construction materials		
Direct CO_2 due to fuel consumption by vehicles transporting construction materials	Y	India-specific CO_2 emission factors from MoEF (2010) and ARAI (2007)
Embodied energy and CO_2 of fuels used	Y	Indian and international coefficient values from TERI (2010) and Edwards *et al*. (2006)
Embodied energy and CO_2 of vehicles/transport modes used to transport construction materials	N	Capital assets; common to several projects/ non-construction activities
On-site impacts		
Direct CO_2 emissions due to on-site fuel consumption (by construction machinery)	Y	India-specific CO_2 emission factors from MoEF (2010) and ARAI (2007)
Embodied energy and CO_2 emissions of fuel used (by construction machinery)	Y	International coefficient values from TERI (2010) and Edwards et al (2006)
Indirect energy consumption (energy consumed during the manufacturing of construction machinery/equipment used on-site)	N	*Rational for not including*: Machinery/equipment are common to several construction projects – need to proportionately distribute embodied energy to all projects where they are used – may not be significant per project
Vegetation removal, carbon sequestration potential lost	N	It is assumed that compensatory vegetation will be planted to make up for the carbon sequestration potential lost
Operations Phase		
Direct energy consumption and CO_2 (tailpipe and embodied) emissions from vehicles moving on the transport corridor	Y	India-specific CO_2 emission factors used from MoEF (2010) and ARAI (2007)
Embodied energy and CO_2 of fuels used	Y	Indian and international coefficient values from TERI (2010) and Edwards *et al*. (2006)

Carbon Sources	Included	Remarks/Source
Indirect energy consumption and CO_2, that is, energy consumed and CO_2 emitted due to the manufacturing and maintenance of rolling stock	N	*Rational for not including:* Vehicles plying on highways are also plying on other roads, such as SHs, MDRs, and urban roads. Apportioning the entire rolling stock embodied emissions to highways is hence not appropriate and not included
Maintenance Phase		
Activities associated with annual and periodic maintenance works: Material consumption (embodied energy and CO_2) Energy use on-site	 Y Y	India-specific coefficients from AEI (2009) International values from Hammond and Jones (2008) India-specific CO_2 emission factors used from MoEF (2010) and ARAI (2007)

Using the methodology as described above, this study focused on estimating the emissions from different phases of a highway's life for specific highway stretches across India. As elaborated in Table 6, the emissions from the highway stretches have been estimated and segregated into the construction phase, maintenance phase, and emissions resulting from the operation of vehicles on the NHs during its life.

This estimation methodology was modelled on an MS Excel-based tool developed to estimate emissions for the different representative projects/stretches. A similar excel-based approach has also been adopted by the World Bank study to estimate the life cycle emissions for the construction and maintenance phases of rail and road projects in the Democratic Republic of Congo.[4]

Table 6 and Table 7 describe the framework of the spreadsheet model used by TERI to estimate project-level CO_2 emissions. The emissions estimated for the different highway stretches using this methodology/ MS Excel-based tool help to generate highway-level emissions factors for different types of highways during the different stages of development and, in particular, during the construction and maintenance stages. These factors are thereafter used to determine an estimate for the total CO_2 emissions of the entire NH network in India as explained in the subsequent sections. A snapshot of data related to a representative NH for the construction and maintenance phases as captured in TERI's excel model is given in Annexure 16.

Table 6: Framework of the spreadsheet model developed for the estimation of project-level CO_2 emissions

Construction/Maintenance Phase												
(1) Construction/Maintenance Materials and Fuels												
Construction Materials used	Unit	Quantity	Source	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle (in specified units)	No. of trips (from source to site)	Fuel type (diesel, CNG, etc.) of vehicle	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/ unloading (hours)	Fuel consumption	Carbon emissions (tonnes)
Soil												
Crushed stones												
Crushed slag												

[4] https://openknowledge.worldbank.org/bitstream/handle/10986/18365/697110P11055700as0Analysis00PUBLIC0.pdf;sequence=1; last accessed in July 2017

Construction Materials used	Unit	Quantity	Source	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle (in specified units)	No. of trips (from source to site)	Fuel type (diesel, CNG, etc.) of vehicle	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/ unloading (hours)	Fuel consumption	Carbon emissions (tonnes)
Reclaimed concrete												
Bricks												
Aggregate												
Water												
Cement												
Fly ash												
Granulated blast furnace slag												
Ready-mix concrete*												
Steel reinforcement												
Joint sealing												
Steel or polymeric synthetic fibres												
Bitumen/ tar												
Cationic bitumen emulsion												
Paint												
Primer												
Fuel/power												
On-site electricity												
Diesel (generators)												
Diesel (machinery and vehicles)												
Petrol												
CNG												
Furnace oil												
LDO												
Kerosene												
LPG												
Natural gas												
Biomass												

(2) Street Furniture														
Type	Quantity per km (numbers., etc.)	Primary materials of which street furniture is made	Weight of primary materials per fixture (if available)	Manufacturer	Source from where street furniture is/was brought					Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/unloading (hours)	Fuel consumption	Carbon emissions (tonnes)
					Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)	Number of trips				
Signages													
Street lights													
Toll gates													
Bus stop shelter (if any)													
Road delineators													
Traffic signals													
Others(specify):													

(3) Movement of Personnel/ Labour							
		Typical mode of travel (for coming to construction site daily)					
Staff/labour	No. of staff/ labour	Vehicle type	Fuel type	Average occupancy	Average daily distance travelled to reach construction site (kms)	Fuel consumption	Carbon emissions (tonnes)
Contractors/engineers/ other staff							
Construction labour							
Equipment operators							

Table 7: Framework of spreadsheet model developed for LCA for operations

Operations Phase										
Vehicle Type	Fuel type	Avg. per day traffic (both ways at the start of project)	Annual traffic growth rate	Technology share - start of project	Technology share - end of project	Technology type Fuel Efficiency	Annual efficiency improvement rate	Total vehicles travelling during lifetime	Total fuel consumed during operation lifetime	Carbon emissions (tonnes)
Cars										
Two wheelers										
Taxis										
Jeeps										
Buses										
Mini buses										
LCVs										
HCVs										
Note: For complete list of construction/maintenance materials, refer the questionnaire in Annexure 3										

2.3 Methodology for estimating CO_2 emissions of the entire NH network

While the methodology proposed and adopted in Section 2.2 is adequate to estimate the emissions from specific highway stretches, the current study also focuses on estimating the emissions from the entire national highway network. A hybrid approach has been adopted for estimating CO_2 emissions of

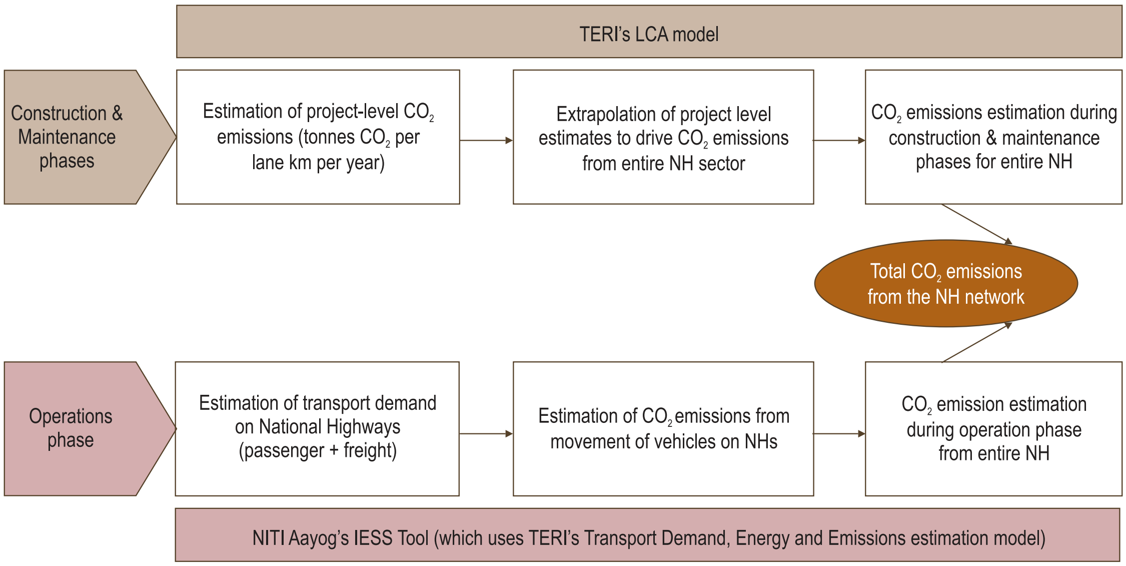


Figure 6: Modelling approach adopted under this study to estimate total (construction, maintenance, and operations) CO2 emissions from India's NH network

the NH sector under this study. The hybrid approach combines the emissions modelling approach for the construction and maintenance stages (Section 2.2) with an independent national transport demand, energy, and emissions modelling approach focused on estimating emissions on account of vehicular operations on highway.

The emissions from the construction and maintenance-related activities on NHs' network have been estimated by scaling up the emissions determined across representative highway sections. The spreadsheet framework given in Section 2.2.2 has been used to calculate the emissions during the construction and maintenance phases. The operation-phase emissions that occur on account of the movement of vehicles on highways have been estimated using the NITI Aayog's India Energy Security Scenario (IESS) tool.[5] IESS estimates the annual transport demand [passenger kms (pkm) and tonne km (tkm) for India by deploying a bottom-up transport demand activity model; traffic (pkm and tkm) on Indian National Highway network has been estimated from the IESS and the resultant CO_2 emissions calculated. The emissions from the two sources, i.e. (i) construction and maintenance, and (ii) operations, have been aggregated to arrive at the total emissions from India's NH network. The two approaches are described in the sections below and in Figure 6.

[5] http://iess2047.gov.in

2.3.1 Construction and maintenance related emissions for the entire National Highway network

Project-level CO_2 estimates—derived using the methodology proposed in Section 2.2.2—have been used to estimate the CF of the entire NH sector. A bottom-up approach for the estimation of construction and maintenance emissions necessitates the need to select highway projects/stretches that could represent the Indian National Highway network. The emissions estimates of these representative highways are then extrapolated to arrive at a national-level CO_2 emission estimate for the entire NH network's construction and maintenance activities.

It was critically important to account for different terrains and climatic conditions prevailing in the country while shortlisting representative highways. These factors play a vital role in determining the method of construction, use of construction technology and different materials, its periodical maintenance, and the efficiency/performance of vehicles during the operations phase. It was hence considered important to select sample highway stretches that represent different terrain and climatic conditions. The following section discusses the importance of considering terrain and climatic conditions while selecting highway typologies/sample highway stretches.

2.3.1.1 Selection of representative NHs: Criteria used

As per the BIS SP 7: 2005, India has been divided into five different climatic zones. These are hot and dry, warm and humid, composite, temperate, and cold. Different climatic zones as well as terrain factors call for different techniques and materials for construction and maintenance of highways; the efficiency or performance of vehicles plying on roads also vary with variations in terrain and climatic conditions.

Terrain is one of the most important parameters that govern the geometric design of the highways and the construction method. For the purpose of designing highways, the terrains have been classified according to the general slope of the area. The Indian Roads Congress (IRC) gives the criteria for terrain classification, as shown in Figure 7 and Table 8.

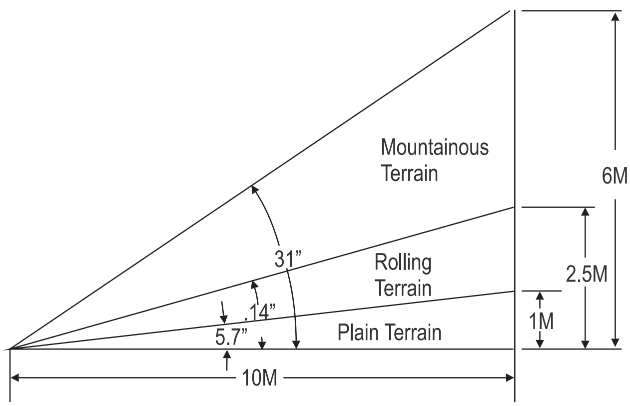


Figure 7: Classification of terrain

Source: IRC (2014)

Table 8: Terrain classification by IRC (Indian Roads Congress, 2014)

Terrain classification	Cross slope (%)
Plain	0–10
Rolling	10–25
Mountainous	25–60
Steep	Greater than 60

Various geometric design elements need to be taken into consideration on account of terrain differences. Factors, such as design speed, vertical alignment, horizontal alignments, etc. vary for different terrains. There are extensive specification codes that are available, such as IRC SP: 48-1998 and IRC SP: 84-2014, which give the guidelines for the design of highways specifically in hilly areas.

In addition to terrain, climatic conditions are also important as far as highway construction and maintenance are concerned. While, there are no special codes specified for construction of roads in coastal and desert regions, there are some mitigation measures or interventions to deal with these conditions that are extensively discussed by the IRC. Constructions in cold climates are captured by codes focussing on hilly areas. Effect of terrain/climatic conditions on the construction and maintenance approaches for highways is discussed in detail in Box 3. The discussion indicates the importance of considering these two factors while selecting highway stretches that are representative of India's NH network.

BOX 3: EFFECT OF TERRAIN/CLIMATIC CONDITIONS ON APPROACHES SUCH AS CONSTRUCTION/ MAINTENANCE

Hilly terrain/High-rainfall regions

- The planning, designing, and construction of highways in hilly terrains are different as compared to the plain terrains and vice versa. In the hilly areas, the villages/habitations are more scattered and the alignment of the road is mostly governed by topographical features, such as curves and bends. Further, the construction involves cutting of hills wherever required. This activity can hamper the natural slope of the area and lead to soil erosion. Various mitigation measures are applied to reduce this impact. The most widespread practices used are: construction of retaining wall, drainage and cross-drainage systems, coping back filling, and various slope-stabilization techniques, such as asphalt mulch treatment, grouting, use of jute and coir meshes. Flexible pavements are typically preferred in hilly regions and the use of rigid pavements is not recommended (Indian Roads Congress, 1998).
- Rainfall and snowfall are usually the main climatic conditions in the hilly regions; coastal regions are also marked with high rainfall durations. It is, therefore, recommended in these regions to add an additional layer

of 225 mm, consisting of a mixture of sand and gypsum, to check salt infestation in the pavements. Also, use of geosynthetic/geotextile materials is recommended. Open graded bituminous surfacing with seal coat containing 1–2%of bitumen content is used in areas with high rainfall. In order to enhance the workability of the bitumen under low temperature conditions, cut back emulsions and cationic emulsions are recommended (IRC-84, 2014).

- Drainage infrastructure plays a key role while undertaking road projects in the hilly, coastal, or regions receiving heavy rainfall. The design of drainage has to be done in accordance with IRC SP: 48-1998.
- In addition to these, there are various design specifications given in IRC SP: 48-1998 for the construction of hilly roads. The permissible design speed for the hilly regions varies from 30–50 km per hour (kmph) because of sharp turns and elevation. Additional right of way can be provided to ensure that sufficient 'sight distance' is guaranteed. In addition, 1.5 m of carriageway can be provided in areas with high snowfall. The highways in these areas require frequent maintenance works to retain safety conditions which can result in higher CF on account of maintenance activities (Indian Roads Congress, 2014).
- In places recording high precipitation or regions with low temperatures, the base and sub-base layers are recommended to be made thicker. This is done in order to reduce the effect of structural changes happening in soil. The additional material requirement as a result, increases the CF of the section.

Extreme temperature conditions

- Use of anti-stripping additives in the bitumen-mix design is recommended in areas with high snowfall. The thickness of the pavement is recommended to be more than the depth of penetration of frost and the wearing surface is recommended to be made using dense bitumen carpet. In regions with extreme climate conditions, use of crush stones aggregates as the base material is recommended. In these, demand for materials increases eventually leading to higher CF on account of more excavation, production, and transportation of materials used in construction (IRC-84, 2014).
- Extreme cold conditions cause two main types of pavement distress. The first one is frost heaving which can cause differential settlement in pavements; and the second is thaw weakening which is caused when ice that enters the lower layers of the pavement, melts. This melted water again alters the physical property of the soil and modifies its bearing capacity causing structural deformity in the pavement, thereby necessitating regular maintenance work (IRC-SP-14, 2004).
- High temperatures cause expansion and contraction and, in the case of rigid pavement, can cause slab curling. Transverse cracks are developed in the case of extreme cold weather conditions. Curling of concrete, frictional stresses, and buckling are some of the pavement failures associated with rigid pavement; in the case of flexible pavement, rutting can happen due to extreme temperature differences. High temperatures, therefore, require better asphalt quality (refer to Table 9). Higher-grade bitumen mix usually has high CF since they have more bitumen content by weight (Indian Roads Congress, 2006).

Table 9: Selection criteria for viscosity-graded bitumen based on climatic conditions (Indian Roads Congress, 2006)

Lowest daily mean air temperature °C	**Highest daily mean air temperature °C**		
	Less than 20	**20–30**	**More than 30**
More than -10	VG-10	VG-20	VG-30
-10 or lower	VG-10	VG-10	VG-20

Source: IRC (2006)

- Extreme climate conditions can also lead to premature deterioration of pavements. For instance, extreme heat is expected to increase highway construction and maintenance cost and the same applies to areas that record high-precipitation levels since high precipitation causes washouts and deranges the surface quality of the pavement.

The following section (2.3.1.2) considers the two criteria—terrain and climatic conditions—for selecting representative highway stretches that have been studied in detail to estimate project-level/stretch-wise CO_2 emissions. These project-level/stretch-wise estimates have been extrapolated to estimate construction and maintenance related to CF of the NH network in India.

2.3.1.2 Processes involved in the selection of representative road stretches

The selection of representative highways involved significant level of rigour as the CO_2 emissions estimates from these highways are extrapolated to arrive at carbon emissions of the entire NH network for construction and maintenance phases. Figure 8 explains the processes involved in the selection of representative NHs. Effort has been made to select highway stretches, which represent different typologies/terrain, type of materials used (flexible and concrete) as well as type of construction (brownfield and greenfield).

As can be inferred from the previous discussion on Figure 8, terrain and climatic conditions have been considered as two important criteria for selecting sample NH stretches. The following section provides a detailed discussion on the approach adopted to select representative highway stretches, along with the final selection of highways for which carbon emissions are estimated.

a. Climate

India is a large country and a diversity of climate types and sub-types exist here. In order to understand the pre-dominant climate types existing in the country, literature on climate classification has been analysed. This analysis shows that various criteria have been adopted for identifying the climate of different zones. Temperature, rainfall, and humidity, are the most widely used parameters for identifying the climate of a particular zone. Classifications, such as Koppen's scheme, climate classification as suggested by the Bureau of Indian Standards (BIS SP 7: 2005), and classifications suggested by different researchers were studied. Table 10 provides an overview of different climate classifications in terms of the number of zones that a particular classification divides the country into and the criteria it employs as the basis of climate classification.

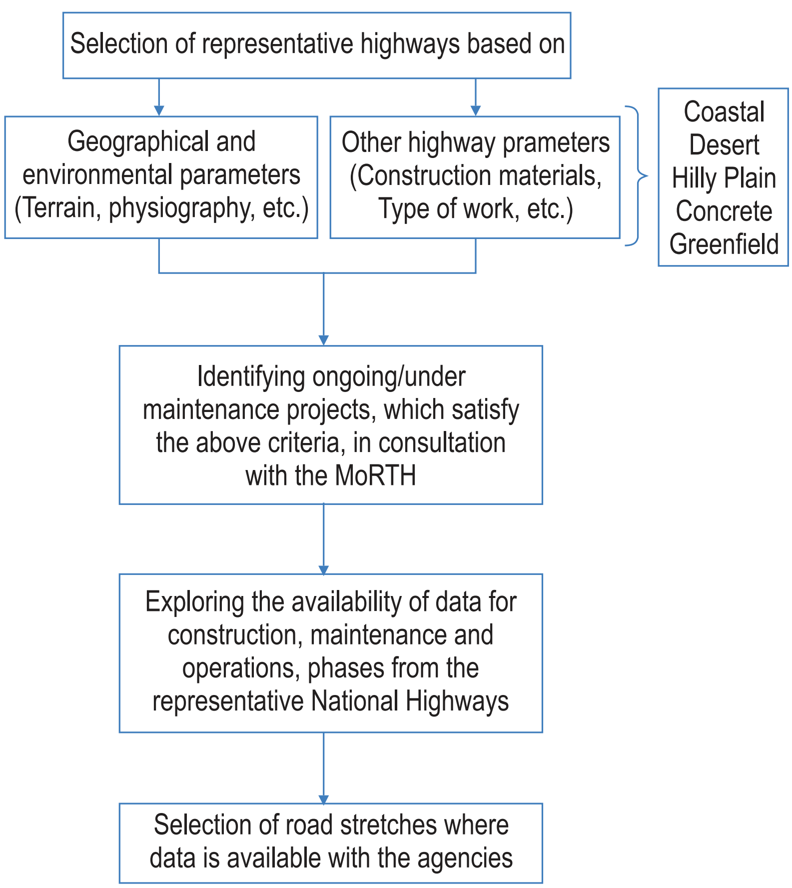


Figure 8: Steps involved for selecting representative National Highways for carbon footprint estimation

Table 10: Overview of different climatic classifications

S.no	Classification type	No. of zones	Criteria	Remarks
1	Koppen's Scheme[6]	9	Mean monthly temperature, mean monthly rainfall, and mean annual rainfall	Internationally accepted
2	Research paper on 'Revisiting climatic classification in India: A district level analysis'[7] (Raju, *et al*., 2013)	7	Moisture Index (derived from parameters, such as average annual rainfall and potential evapotranspiration)	Available at district level; Recent data used - 1971-2005
3	BIS SP 7: 2005[8]	5	Temperature, humidity, Rainfall (annual)	Simple to follow
5	Dr R L Singh[9]	10	Temperature conditions of the hottest and the coldest months and average annual rainfall	Done in 1971

Source: Compiled by TERI

It was concluded that for the purpose of the current study, BIS classification would be followed as this classification has been specifically drawn for the country by a recognized government institution. This classification is widely used by civil engineers and architects for the purpose of undertaking civil works, etc. Box 4 provides the key features of BIS climate classification.

As per the BIS SP 7: 2005, India has been divided into five different zones, namely, hot and dry, warm and humid, composite, temperate and cold (Figure 9). Composite climate typology is the most predominant in the country and the temperate classification is almost inexistent. For the purpose of highway selection, highways from the four prevalent climate typologies, that is, hot and dry, warm and humid, cold and composite were considered in highway selection.

BOX 4: BIS SP7:2005 CRITERIA FOR CLIMATE CLASSIFICATION

BIS SP 7: 2005

Criteria for climate classification

Under this classification, a place is assigned to one of the first five climatic zones only when the defined conditions exist in that place for more than six months. In cases where none of the defined categories can be identified for six months or longer, the climatic zone is called composite.

Table 11: Criteria for climate classification under BIS SP 7: 2005

Climate	Mean monthly maximum temperature (degree C)	Relative humidity (percent)
Hot and dry	> 30	< 55
Warm and humid	> 30 > 25	> 55 > 75
Temperate	25-30	< 75
Cold	< 25	All value
Composite	This applies when six months or more in a year do not fall within any of the above categories	

[6] http://www.geographynotes.com/articles/climatic-regions-of-india-with-maps/976

[7] http://www.currentscience.ac.in/Volumes/105/04/0492.pdf

[8] http://mnre.gov.in/solar-energy/ch2.pdf

[9] http://www.yourarticlelibrary.com/geography/climate-of-india-2-major-climatic-regions-of-indian-climate/13851/

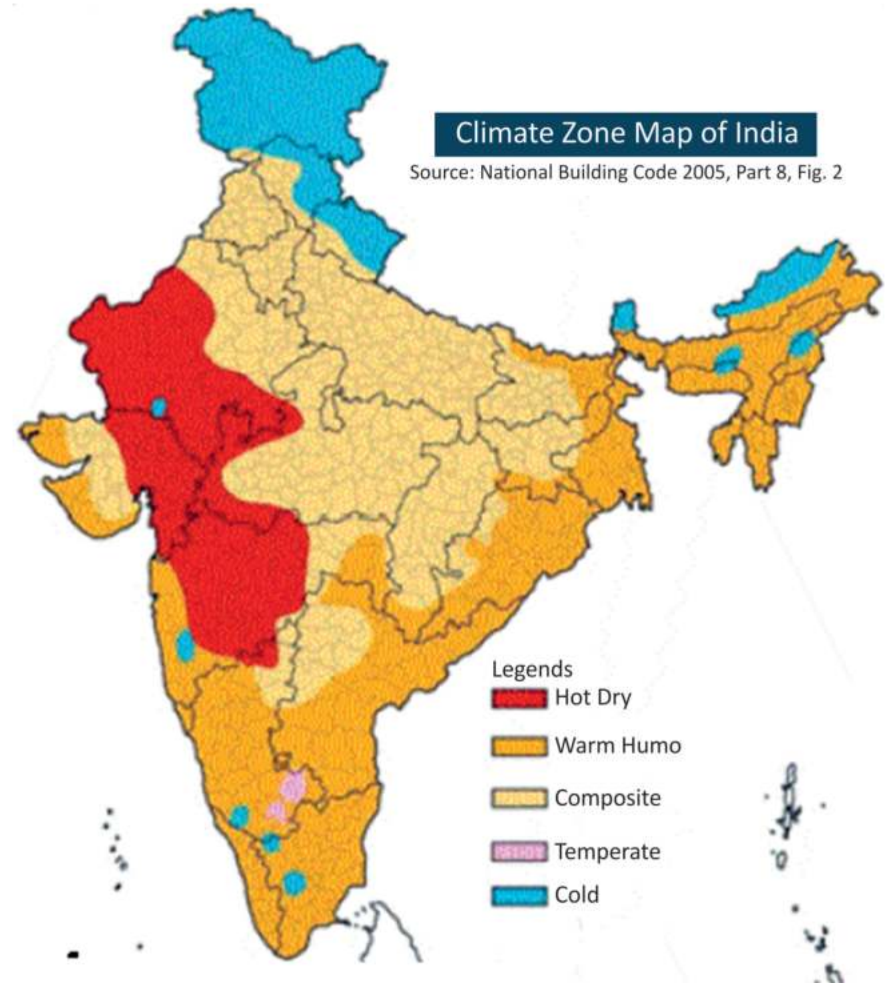


Figure 9: Five climatic zones of India

b. Physiography

India can be divided into the following distinct physiographic regions:

v. The Great Plains
vi. The Himalayas
vii. The Indian Desert
viii. The Deccan Plateau
ix. The Western Coast
x. The Eastern Coast
xi. The Islands

It is seen that physiographic regions also correspond with the climate classification of the country. The Great Plains mostly correspond with the composite climate type, the Himalayas with the cold climate, the Indian desert with the hot and dry climate, the Deccan plateau with the composite and warm and humid climate, and the Western and the Eastern coasts correspond with warm and humid climate. The islands were not considered separately as it was anticipated that conditions prevailing in islands would be similar to the ones existing in the coastal regions.

c. Terrain

For the purpose of selecting representative highway stretches, it was decided that highways passing through plains, rolling, and hilly areas would be studied as the majority of the highways in India fall under these categories. A terrain-wise distribution of NHs in India is given in Table 12. The data has been provided by the regional offices (ROs) as well as project implementation units (PIUs) of the NHAI in various states to the MoRTH for NHs covering a length of 34,016 km. Of this, about 96% fall under the plain category and 4% are mountainous and steep (Annexure 6).

Highway parameters: Pavement type

The NHs in India predominantly use bitumen pavement. Discussions with the MoRTH and NHAI officials revealed that there are a few NH stretches that use cement concrete and composite pavements, NH 2, NH 12, and NH 14 are amongst these. Hence, highways with bitumen as well as concrete/composite pavements were considered while selecting sample highway stretches.

2.3.1.3 Selected case study highways

Drawing from the previous discussion, the following highway typologies were selected as representative highway typologies on the basis of environmental and geographical parameters:

- The Great Plains and the Deccan Plateau: Composite climate, plain terrain
- The Himalayas: Cold climate, hilly terrain
- The Indian Desert: Hot and dry climate, plain terrain
- Coastal: Western and eastern coasts, hot and humid, plain terrain

The representative highway stretches that were selected for carrying out a detailed exercise of estimating the life cycle CF of NHs stretches are listed in Table 12.

Table 12: Details of selected stretches for the study

S. No.	Environmental and geographical parameters (Pavement construction type)	Description of type of work	Lifecycle stage	Stretch	Length (km) for which data was provided by agencies
1	The Himalayas – cold climate – hilly (asphalt)	Road protection work on hill side and valley side	Construction	Chamoli-Rudraprayag NH-87E^ (km 220 to km 234)	15
		Construction of a 2-lane carriageway with geometric improvements	Construction	Herbertpur-Barkot km 101 to km 106.87 on NH-123^	5.9
		Operations on a 1.5 lane road	Operations	Rudraprayag-Gaurikund section NH-109	76
		Improvement/strengthening of damaged road (annual maintenance) (single lane)	Annual Maintenance	Road between km 188 to km 211 on NH-94	23
		Single-lane road periodic maintenance	Periodic Maintenance	Chamoli-Rudraprayag section of NH-87E^ (Adalikhal to Adibadri)	17
2	The Indian Desert – hot and dry climate – plain (asphalt)	Widening and strengthening of a 2-lane highway (7m to 10 m with 1m shoulders on either sides)	Construction	Jodhpur-Pokhran NH-114	139.6
		Widening and strengthening of a 2-lane highway (7m to 10 m with 1m shoulders on either sides), traffic estimates for completed highway	Operations	Jodhpur-Pokhran NH-114	139.6
		4-lane highway maintenance	Annual Maintenance	Jodhpur-Pali NH 65	71.53

Table 12: Details of selected stretches for the study					
S. No.	Environmental and geographical parameters (Pavement construction type)	Description of type of work	Lifecycle stage	Stretch	Length (km) for which data was provided by agencies
3	The Great Plains and the Deccan Plateau – composite climate – plain (asphalt)	Widening and strengthening of a 2-lane highway (7m to 10 m with 1m shoulders on either sides)	Construction	Raebareli-Banda NH-232	133
		Operations on a 2-lane road	Operations	Lucknow-Raebareli NH-24B	70
		2-lane road (annual maintenance)	Annual Maintenance	Lucknow-Raebareli NH-24B	70
		4-lane road (periodic maintenance)	Periodic Maintenance	Orai-Barah NH-25 & 2	62.8
4	Coastal – (western coast and the eastern coast) – hot and humid – plain (asphalt)	Upgradation work of 4 lane to 6 lane	Construction	Bhubaneshwar-Chandikol NH-16	67
		Operations on 4/6-lane road	Operations	Bhubaneshwar-Chandikol NH-16	67
		4-lane highway (annual and periodic maintenance)	Annual and Periodic Maintenance	Ichapuram-Bhubaneshwar NH-16	185
5	Concrete and composite pavement stretch	4-lane to 6-lane widening	Construction	Chakeri-Etawah NH-2^**	160.2
		Operations on a 6-lane road	Operations	Mumbai-Pune Expressway	94.6
		6-lane highway (annual and periodic maintenance)	Annual and Periodic Maintenance	Mumbai-Pune Expressway	94.6
6	Greenfield highway (bitumen)	4-lane greenfield construction	Construction	Patna-Bakhtiyarpur NH-30	50.65
Note: ^ Old numbering; **Stretch has both concrete and bitumen pavements; periodic maintenance data for desert terrain could not be made available					

As can be observed in Table 12, multiple representative highways had to be selected for a particular terrain as no single project provided the data pertaining to all the life phases. For instance, the data for plain terrain (with composite climate) was collected from three NH projects/stretches; construction data was collected for the Raebareli-Banda section of NH-232, annual maintenance and operations data was collected for the Lucknow-Raebareli (NH-24B) section; and periodic maintenance data was collected for the Orai-Barah section (NH-25 & 2). While multiple highway projects/stretches were used to collect the data for a particular terrain type, it was ensured that the selected projects/stretches were in close vicinity of each other so that the terrain and climate conditions did not vary significantly.

2.3.1.4 Extrapolating stretch-wise CO_2 estimates to estimate CO_2 emissions of construction and maintenance activities of entire NH network

A terrain-wise lane km data was required to extrapolate and scale up project-level/stretch-wise CF estimates of the NH network level. There was, however, a limitation in the data since the terrain-wise segregation to the level of detail as explained in section 2.3.1.2 was not available for the entire NH network.

Noting such limitation, the NH network was segmented into two simpler terrain categories—plains and hilly.[10]

All project-/stretch-wise CF numbers were categorized as either plain or hilly. This was done to scale up the estimates to the NH network level. The NH network was also required to be divided into two categories—plains and hilly. However, information about the distribution of plain and hilly roads for the entire NH network was also not available, and the same had to be estimated from the best-possible data sources available in this regard (Table 13).

The distribution of about 34,000 km of a total 103,933 km of NHs was made available by the MoRTH, along with the average lane kilometres under each type (Annexure 6). Given that different highway stretches are of different dimensions, ranging from a single lane to six-lane to eight-lane, the total highway network was distributed into plains and hilly.

The two different data-sets made available by MoRTH and NHAI for this purpose are as follows:

- Terrain-wise lane-wise length of NHs covering about 34,016 km (1,06,490 lane km) *(Source: MoRTH, 2016)*
- State-wise lane-wise length of NHs covering a total of about 75,500 km (2,96,112 lane km) *(Source: NHAI, 2016)*

Table 13: Estimated terrain-wise lane km of NHs

Terrain	2016–17	2030–31
Plain	317,040	545,818
Hilly	13,210	22,742
Total lane km	**330,250**	**568,561**

Source: MoRTH

Based on the numbers from these sources, a share of only about 4% of the total NH length in terms of lane km was found to be under hilly terrain, and the remaining under plains. This percentage share of hilly- to plain-lane kilometres was used to derive the total absolute NH lane kilometres under these two broad terrain categories and to estimate the CF of the entire NH network. The key assumptions used for the estimation of CO_2 emissions from the construction and maintenance phases are described in Annexure 11.

Note: As stated earlier, terrain and climate zone-wise lane km data was required to extrapolate and scale up project-level/stretch-wise CF estimates to derive emissions for the entire NH network. The terrains/climate zones for which lane km distribution of NH network was required are:

- Plain terrain – Composite climate
- Hilly terrain – Cold climate
- Plain terrain – Hot and dry climate (desert)
- Coastal (western coast and the eastern coast) – Hot and humid climate

Given the lack of data, the NH lane km were divided into two broad categories: plains (96%) and hilly (4%); coastal and desert lane km distinction was not done on account of lack of data. The construction and maintenance emissions for the entire NH network have been estimated using this categorization of NH lane km and the results are reported in Chapter 3, 'Estimation of CF: Results'. However, in order to understand the difference in emissions that could occur on account of better data, that is lane km division into plan, hilly, desert, and coastal, TERI carried out a rough analysis to derive the lane km distribution across all these terrains. NH network map was overlaid with climate and physiographic zones in GIS to derive the NH length under plain, hilly, desert, and coastal zones (Annexure 7) and used to drive lane km under these categories. The resultant distribution of lane km is as follows:

i. Plains - 77%

ii. Hilly - 7%

iii. Coastal - 13%

iv. Desert - 3%

TERI estimated the NH network emissions (construction and maintenance emissions) using the above distribution, the results of which are provided and discussed in Annexure 16.

2.3.2 Operations related emissions for entire NH network

As stated earlier, the emissions on account of movement of vehicles on NHs have been estimated by:

[10] Lane km data for rolling terrain is also available, however, since there are no significant differences in the method of highway construction in the rolling terrain and plain terrain, the stretches under rolling terrain have been assumed to fall under the plain terrain..

First, estimating the traffic on the NH network in the country, and thereafter estimating the CO_2 emissions on account of movement of this traffic.

A bottom-up/stretch-based approach, like in the case of construction and maintenance emissions, estimation was not considered appropriate for the operation-phase emissions estimation, as there were several issues with traffic data being collected for different projects. The traffic data for representative stretches that were selected was not consistent, as somewhere it was DPR-estimated traffic data, while at other places it was toll data for a particular month/year. Also, for the estimation of emissions from operations on highways, it was felt that the sample size of the different highways was not adequate and ideally traffic data of many more highway stretches representing different patterns/levels of traffic should be collected, which was difficult in the study period. Availability of traffic data for NHs was also enquired from the NHAI, MoRTH, and Indian Highways Management Company Limited (IHMCL). It was, however, found that a comprehensive database on traffic movement on NHs was currently not available.

The HDM-4 model, developed by the World Bank, was also considered under the study to estimate NH-level emissions. However, it was found that even though HDM-4 is a comprehensive model for project level CO_2 emissions, which takes into consideration the pavement conditions while calculating emissions, it is challenging to calculate CO_2 emissions for the entire National Highway network using HDM-4. The volume of input data required for the HDM-4 model for estimating project-level emission calculation is significantly high. Several other life cycle analysis tools, models, and methodologies were also reviewed as part of the study, and these have been listed in Annexure 14.

After the review of several methodologies, a bottom-up approach of estimating traffic on NHs was deemed appropriate for the current purpose. As stated earlier, NITI Aayog's India Energy Security Scenario (IESS) 2047 tool provides transport demand estimates for road transportation in the country. The traffic estimates for NHs, that is passenger km (pkm) and tonne km (tkm) were derived from this tool, which uses TERI's Transport Demand, Energy and Estimation Model to estimate CO_2 emissions (Box 5). NITI Aayog has provided a list of documents,[11] including those for the transport sector, which have been used to estimate emissions. TERI has made assumptions, shared in Annexure 12, to arrive at the CO_2 emissions on account of NHs during the operations phase. The Figure 10 given below indicates the transport segments considered to arrive at NH-level operations phase CO_2 emissions under the study.

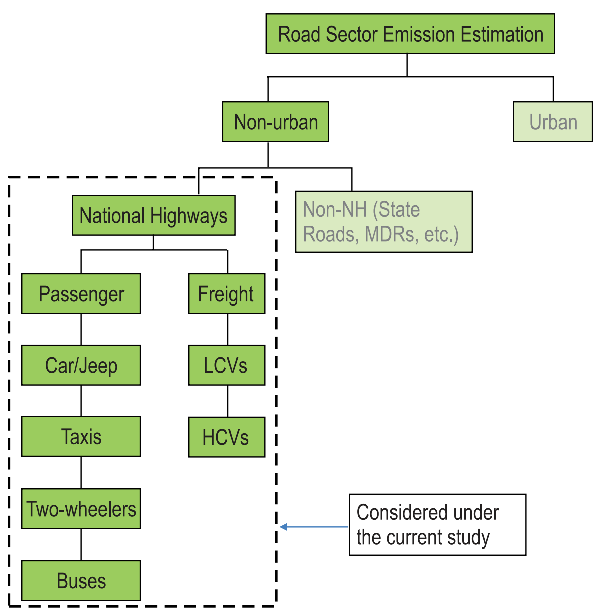


Figure 10: Transport segments considered to estimate NH-level operations phase emissions

[11] Documents: http://www.indiaenergy.gov.in/iess/default.php ; last accessed on August ; Model: http://iess2047.gov.in/pathways/; last accessed on July 4, 2017

BOX 5: TERI TRANSPORT DEMAND, ENERGY, AND EMISSIONS ESTIMATION MODEL

TERI has developed a national, macro-model for estimating energy demand and resultant emissions from the passenger and freight transport sector in India. A bottom-up approach has been used to estimate total volumes of passenger and freight transport demand in India.

The model has been widely used and accepted by several agencies of the GoI for the estimation of operational emissions from the transport sector in India. Some of the activities where the model was used are as follows:

- India Energy Security Scenarios (IESS) 2047, Planning Commission (now NITI Aayog), Government of India (2013–14)[12]
- India Low Carbon Inclusive Growth Committee Report, Planning Commission, Government of India (2014)[13]
- Modelling India's Nationally Determined Contributions (INDC) as submitted to the United Nations Framework Convention on Climate Change (UNFCCC), Ministry of Environment, Forest and Climate Change (2014–15)[14]

The bottom-up activity model starts with the total stock of different types of vehicles, and then uses the utilization and occupancy levels of different vehicle types to determine the mobility across India. The model is flexible and can be updated to reflect changes in major transport policy, technological advancements, new and updated data, etc. that might affect the energy demand from the transport sector. The model relies on a large number of data parameters related to technology-wise transport activity based on survey and field data, and is further strengthened by appropriate assumptions based on thorough research and stakeholder consultations.

The model is capable of assessing the cumulative changing impact of factors, such as economic growth, population growth, increasing vehicle ownership levels, and increased urban transport movements, to take into account the impact of urbanization on transport energy demand, along with factors, such as technological improvements in efficiency, reduction/saturation of freight lead, and increase of passenger lead, mode shares, and fuel-type shares. The key outputs are indicators of transport demand, such as passenger and freight-kilometres, fuel consumption, energy, and emissions volumes from the domestic transport sector in India.

12 http://iess2047.gov.in/

13 http://planningcommission.nic.in/reports/genrep/rep_carbon2005.pdf

14 http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf

3 Estimation of Carbon Footprint: Results

3

Estimation of Carbon Footprint: Results

As discussed in the previous chapters, carbon emissions from National Highways can be segregated into three broad phases: the construction phase, the maintenance phase, and the operations phase. The current study analyses the emissions emanating from these three phases of NHs in India.

The study first focuses on estimating the construction- and maintenance-related emissions from specific stretches of highways across India, followed by estimating these emissions from across the total NH network in the country. This chapter starts with an estimation of the CO_2 emissions from the construction and maintenance activities from specific sections/ stretches of highways across different terrains in the country. Thereafter, the emissions resulting from these phases for the entire highway network are estimated by scaling up the results and emissions factors obtained from the highway stretch specific estimation exercise.

Estimates of emissions as a result of operations of vehicles on the NH network are drawn from NITI Aayog's India Energy Security Scenario (IESS) tool, as described in the previous chapter. The results from the same are presented in this chapter, followed by estimates of aggregate emissions from the total NH network.

3.1 CO_2 emissions from construction and maintenance activities

Construction and maintenance activities through the lifetime of a highway generate emissions due to factors, such as embodied carbon in the materials used, emissions resulting from the use of fuels, such as electricity and petroleum products for operating equipment on-site, and also for the movement of materials, equipment, and labour to and from the construction site.

The study team collected primary data from across different highway stretches at different stages of their development (refer to 2.3.1.3). Primary data from the selected highways was collated and analysed to determine the emissions factors for construction- and maintenance-related activities; the estimated CO_2 emissions/emission factors are reported in section 3.1.1. These emissions factors were used to estimate the total CO_2 emissions from the construction- and maintenance-related activities for the existing NH network; the results are reported in section 3.1.2.

3.1.1 Project-level/stretch-wise CO_2 emissions from construction and maintenance activities

As stated in the previous chapter, a bottom-up approach was adopted to estimate the CO_2 emissions from construction- and maintenance-related activities from the NH network in India. CO_2 emissions have been estimated for selected highway stretches which have then been extrapolated to estimate the construction- and maintenance-related CF of the entire NH network. A critical element in this bottom-up approach was determining the project-level/stretch-wise CO_2 estimates from select highways using the methodology proposed in section 2.2.2 of Chapter 2.

Primary data for each of these project-level highways—about materials, transport of materials, and the intensity of their use during the construction and maintenance phases—was collected from multiple sources, such as the MoRTH, NHAI, PWD officials, and site contractors using the questionnaires given in Annexure 3. The data was then used to calculate emissions from the construction and maintenance phases. Snapshots of emission calculation for construction and maintenance phases was done using TERI's excel-based model as given in Annexure 14.

This primary data was analysed and used to estimate CO_2 emissions from different phases of the highway's life using an excel-based model developed for this purpose, as explained in section 2.2.2. The key results for CO_2 emissions from the construction and maintenance activities of the different highway stretches are provided in Table 14. The estimates are in terms of tonnes of CO_2e emissions per lane km per year. These estimates were derived based on the data provided by site officials/contractors responsible for the construction and maintenance of the selected projects.

Table 14: Summary of CO_2 emission estimates for the selected NHs (tonnes CO_{2e} per lane km per year)

Sr. no.	Stretch	Pavement type	Construction emission (tonne CO_2e per lane km per year)	Maintenance emission (tonne CO_2e per lane km per year)	
				Annual maintenance	Periodic maintenance
1	6 laning of Chandikhole-Bhubaneshwar section of NH-16	B	168.12	-	-
2	Raebareli–Banda (NH-232)	B	22.72	-	-
3	Jodhpur–Pokhran (NH-114)	B	51.58	-	-
4	Lucknow–Raebareli Section of NH-24B	B	-	2.11	-
5	Bhubneshwar–Ichapuram NH-16	B	-	1.52	1.50
6	Development and operation of Jodhpur - Pali section of NH-65 on DBFOT basis	B	-	2.20	-
7	Mumbai–Pune expressway	C	-	13.22*	
8	Orai–Barah section of NH-24	B	-	-	3.31
9	Chamoli–Rudraprayag section from km 200.00 (Adalikhal) to km 217.00 (Adibadri) on NH 87-E	B	-	-	21.21
10	Road protection work on hill side and valley side in km 220 to km 234 on NH-87 Ext. (New NH-109)	B	63.44	-	-
11	Construction of a 2-lane carriageway with geometric improvements from Herbertpur to Barkot km 101.00 to 106.87 on NH-123	B	93.44	0.63	-

B: Bitumen; C: Concrete; *Annual and periodic maintenance; **The average figure for maintenance does not include outliers (Mumbai–Pune expressway and Chamoli–Rudraprayag section)

Source: TERI Analysis

3.1.1.1 Key findings from project-level estimates of construction and maintenance emissions

CO_2 emissions estimated from construction-related activities of sample/representative highways range from 22.7 to 168.1 tonnes CO_2e per lane km per year, with an average of 79.86 tonnes CO_2e per lane km per year. The emissions estimate of 168 tonnes CO_2e per lane km per year for the Chandikhole–Bhubaneshwar section of NH-16 could be attributed to higher use of steel and bitumen, which have significantly high-embodied energy coefficients (refer to Table 17). The annual maintenance-related activities result in CO_2 emissions in the range of 0.63 to 2.1 tonnes CO_2e per lane km per year (average of 1.62 tonnes CO_2e per lane km per year), while the periodic maintenance-related activities result in CO_2 emissions in the range of 1.5 to 3.31 tonnes CO_2e per lane km per year (average of 2.4 tonnes CO_2e per lane km per year).

A comparison of these emissions estimates with other international and Indian studies highlight that the emissions figures on account of the maintenance phase (both annual and periodic maintenance combined) are in comparable range (Table 15). However, the estimates of the construction phase of the emissions appear to be on the higher side when compared to previous studies carried out in India.

Table 15: Comparison of emission estimates in previous Indian studies/literature and the current CF study (tonnes CO_2 per lane km per year)

Phase		Estimate from literature - Indian studies	Estimate from the current study
Maintenance	Annual	2.8–6	0.6–2.1
	Periodic		1.5–3.3
Construction		24–29	22.7–168.1

Note: Does not include outliers in the maintenance data

Source: TERI Analysis

A detailed exploration into the factors responsible for construction-related emissions (Table 16), highlight that construction activity-related emissions occur mostly on account of embodied CO_2 in construction materials, transport of construction materials, and debris to-and-from the site, on-site energy usage for running construction equipment, hot-mix plant operations, operations of construction vehicles and equipment, on-site offices, etc.

While the share of emissions due to these three activities are found to be varying from project to project, CO_2 emissions on account of embodied carbon in materials is the dominant source of emissions for this phase with shares in a wide range of 72% to 95.4% of the total construction phase for the sample projects considered as part of this exercise (refer to Figure 11).

Table 16: Emissions on account of embodied CO_2 of materials, on-site energy consumption, and movement of materials during the construction phase of representative highways (tonnes CO_2)

Construction Phase	Chandikhole-Bhubaneshwar NH-16	Raebareli-Banda NH-232	Jodhpur-Pokhran NH-114	Chamoli-Rudraprayag NH-109 (New)	Herbertpur-Barkot NH-123
A. Embodied CO_2 – Materials					
Soil brought to site from outside	6,240.00	5,226.48	7,776.00	-	-
Coarse aggregate	11,960.00	4,178.80	1,149.20	141.18	6.76
Fine aggregate	1,622.40	6.76	390.62	86.19	26.52
Bitumen/tar	9,790.00	7,205.00	15,994.00	-	7.70
Natural sand	8,874.00	-	12.65	-	-
Ordinary Portland Cement	2,280.00	7,932.50	1,037.40	3,735.69	9.50
Gravel	-	2,626.75	-	-	-
Steel reinforcement	3,21,316.80	2,000.20	-	65.10	219.00
Ready-mix concrete*	-	6,584.35	814.47	-	-
Soil removed from site (not used on site)	-	2,213.57	1,680.00	-	2,803.20

Construction Phase	Chandikhole-Bhubaneshwar NH-16	Raebareli-Banda NH-232	Jodhpur-Pokhran NH-114	Chamoli-Rudraprayag NH-109 (New)	Herbertpur-Barkot NH-123
Cement lime/ limestone dust, etc.	-	-	501.54	-	-
Crushed stones	-	-	885.82	-	47.84
Others	-	577.50	218.35	-	-
Total (A)	3,62,083.20	38,551.92	30,460.05	4,028.15	3,120.52
B. On-site energy consumption - CO_2 emission					
Electricity	-	-	-	-	-
Diesel (generators)	8,119.44	-	387.44	-	5.95
Diesel (machinery and vehicles)	12,547.24	783.44	1,502.98	102.58	14.34
Petrol	-	-	-	-	-
Furnace oil	-	-	1.12	-	-
LDO	6,985.94	-	-	-	-
Kerosene	-	-	-	-	-
Total (B)	27,652.62	783.44	1,891.54	102.58	20.30
C. Transport of materials, fuels, etc. - CO_2 emission					
Coarse aggregate	9,431.67	7,225.80	2,291.27	15.91	2.50
Fine aggregate	427.89	4.79	649.74	9.71	9.82
Gravel	-	4,542.06	-	-	-
Soil brought to site from outside	829.99	36.69	89.66	-	-
Soil removed from site (not used on site)	-	7.55	98.94	-	98.42
Crushed stones	-	-	379.10	-	17.71
Natural sand	2,629.15	-	21.63	-	-
Bitumen/tar	807.69	814.36	1,890.66	-	0.57
Cationic bitumen emulsion	-	93.25	12.56	-	-
Ordinary Portland Cement	4.52	52.80	32.93	124.48	0.03
Water	-	0.77	3.76	-	-
Ready-mix concrete*	-	408.92	3.30	-	-
Chemical Admixture	-	4.25	2.17	-	-
Cement lime/ limestone dust, etc.	-	-	0.68	-	-
Others	4,225.71	1,008.90	80.50	1.24	0.32
Total (C)	18,356.62	14,200.15	5,556.89	151.34	129.37
Grand total (A+B+C)	4,08,092.45	53,535.51	37,908.48	4,282.08	3,270.19

Source: TERI Analysis

As can be observed in Table 16, the key contributors to CO_2 emissions from embodied CO_2 in materials include bitumen, aggregate (coarse and fine), earthwork, cement, and steel. These materials have high embodied/process energy consumption which results in high indirect CO_2 emissions. The relatively higher share of embodied carbon of materials was also witnessed under another Indian study TERI (2012). Under this, the construction of the 83 km Rohtak–Bawal section in Haryana reported 2,300 tonnes

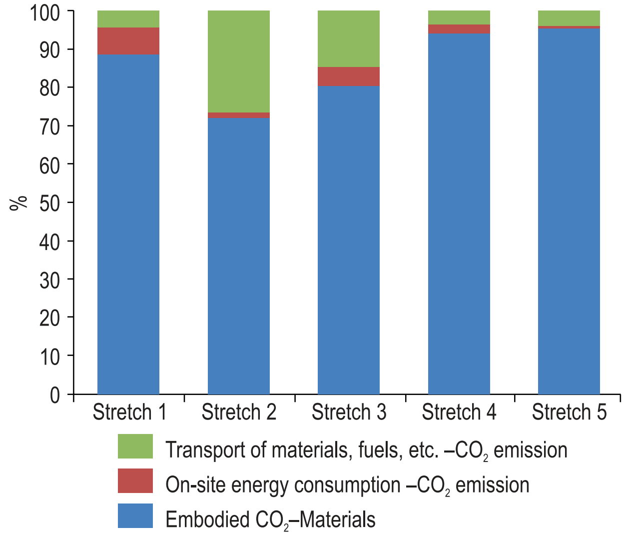


Figure 11: Stretch-wise emission share of transport of materials, fuel, etc.; on-site energy consumption; and embodied materials on account of construction

Source: TERI Analysis

(67% of total emissions) per km of CO_2 emissions on account of embodied CO_2 of materials used, and combined CO_2 emissions on account of on-site energy consumption and transport of materials from source to site was reported at about 1,100 tonnes (33% of total emissions) per km.

Table 17 provides the embodied energy coefficients of some of the key construction materials commonly used in highway construction. Mitigation of carbon emissions resulting due to the use of these materials would require either replacement of these materials with appropriate low-carbon alternatives or reducing the embodied/process energy intensity of these materials. Alternatively, even reducing the quantity of these materials in construction work could be a solution to reduce the emissions resulting from these energy-intense materials. The subsequent chapter (Chapter 4) focuses on potential low-carbon interventions for the construction phase and provides recommendations on the interventions that are possible in this context.

Table 17: Embodied energy coefficients of key construction materials

Material	Embodied energy coefficient (EE) - MJ/kg
Soil brought to site from outside	0.450
Soil removed from site (not used on site)	0.450
Natural sand	0.081
Gravel	0.083
Laterite	0.083
Kankar	0.083
Crushed stones	0.083
Crushed slag	1.600
Reclaimed Concrete	0.750
Cement lime/ limestone dust, etc.	5.300
Bricks	3.000
Coarse aggregate	0.083
Fine aggregate	0.083
Water	0.010
Ordinary Portland Cement	5.500
Portland-Pozzolana Cement	3.680
Portland slag cement	3.680
Chemical admixture	70.000
Fly ash	0.100
Granulated blast furnace slag	1.600
Silica fume	2,355.000
Ready-mix concrete*	0.750
Steel reinforcement	20.100
Other steel	20.100
Bitumen/tar	51.000
Cationic bitumen emulsion	51.000

Material	Embodied energy coefficient (EE) - MJ/kg
Paint	70.000
Fuel/Power	
On-site electricity	3.600
Diesel (generators)	35.800
Diesel (machinery and vehicles)	35.800
Petrol	32.200
CNG	53.600
Furnace oil	35.104
LDO	35.104
Kerosene	36.108
LPG	26.000
Natural gas	53.600
Biomass	15.000
Source: AEI 2009 and Hammond and Jones 2008-	

Other than embodied carbon in materials used for construction and maintenance, the other factor that results in large volumes of emissions is on the account of movement of materials from the source to the site of consumption. For instance, on stretches such as the hilly section between Chamoli–Rudraprayag (km 200 to km 217), the CO_2 emissions on account of periodic maintenance is estimated to be 21.1 tonnes per lane km per year which is mainly due to longer lead for the transportation of materials (bitumen and fuel) as well as on-site fuel consumption.

As can be observed in Figure 12, transport of aggregate (coarse and fine) is found to have a large share in emissions on account of transportation of materials. The average lead of sources for aggregate materials across the three highway sections under the study was found to be 84.8 km[1] (Figure 12). A reduction in distances moved (also referred to as 'lead') of bulk commodities such as aggregates, and moving such commodities by energy-efficient modes, such as waterways or railways where possible, could significantly reduce the emissions from the movement of materials for both the construction and maintenance phases of the highways.

The potential of reduction in the CO_2 emissions on account of shifting aggregate movement from road to rail is highlighted with the help of a project example from Uttar Pradesh in Chapter 4, 'Reducing Carbon Footprint of National Highways: Potential Interventions' (section 4.2.5).

Apart from CO_2 emissions occurring on account of embodied carbon in materials and transport of materials, on-site energy-consumption activities, such as the use of construction machinery and equipment, production of bituminous and concrete mixtures, etc. are also found to contribute to emissions from the

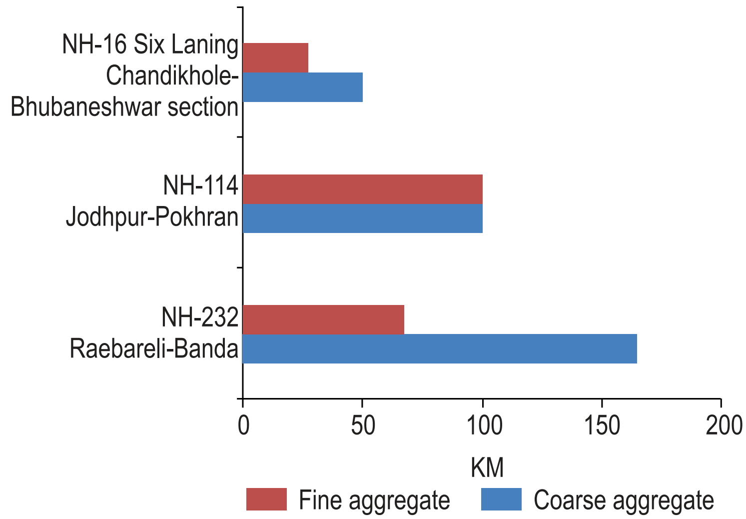
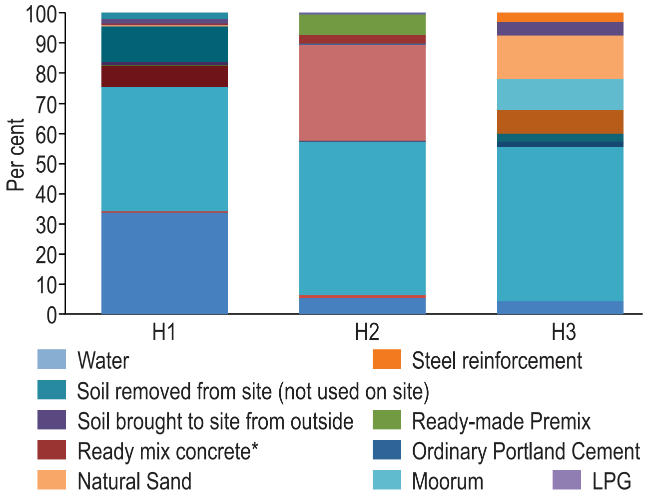


Figure 12: Lead distance for sourcing aggregates for projects involving construction activities

[1] An average figure does not include lead distance for sourcing aggregates for projects in the hilly terrain.



H1	NH-114 Jodhpur–Pokhran
H2	Raebareli–Banda NH-232
H3	Upgradation from four to six lanes of Chandikhole–Bhubaneshwar section of NH-16

Figure 13: CO2 emissions occurring on account of transportation of materials, fuels, etc. to and from construction site – share of different construction materials

construction and maintenance phases of highways. The sample highway stretches considered for this study highlight that CO_2 emissions on account of operations of on-site machinery and equipment result in emissions in the range of 0.6% to 6.8% during the construction phases of the projects. Interventions to reduce CO_2 emissions from such activities are discussed in the next chapter.

The factors affecting emissions resulting from the maintenance phase of highways are similar to that from the construction phase. Maintenance-related emissions from annual and periodic maintenance activities for the representative stretches considered for this study are found to be in the range of 0.6 and 3.3 tonnes of CO_2e per lane km per year (not including the Mumbai–Pune expressway - 13.2 tonnes CO_2 per lane km per year and Chamoli–Rudraprayag section - 21.2 tonnes CO_2 per lane km per year), with an average of about 1.7 tonnes CO_2 per lane km per year. The estimates are comparable to the ones that are derived in comparison to the past Indian and international studies (Table 15 and Annexure 1). In addition to the factors appearing in the construction phase, the number of cycles of periodic maintenance also has a large implication on the resulting emissions from this phase in the life of the highway.

There is a potential to reduce these periodic maintenance-related CO_2 emissions by adopting green technologies and practices such as micro-surfacing (especially by the BOT operators). Such preventive maintenance techniques help in extending the lifetime of road pavements, thereby delaying the need for major maintenance/rehabilitation and, consequently, the emissions resulting from the maintenance phases of the highways. Some of the preventive maintenance measures that could be adopted for Indian highways are discussed in the subsequent chapter.

Well-constructed and well-maintained highways not only consume lower volumes of materials over their lifetimes, but the good-riding quality resulting from the same also lead to higher vehicle efficiencies and lower emissions as a result of vehicle operations. Conversely, the bad-riding quality of road pavements could lead to increased consumption of fuel by vehicles on account of increased rolling resistance (Green *et. al.*, August 2013).

This phenomenon is examined in Chapter 5, 'Good-quality vs Bad-quality National Highways: Life Cycle Emission Analysis', which explores the potential impact on fuel savings and emissions reductions of maintaining good-quality versus bad-quality highways using the case study of a selected National Highway stretch of the NH-24 in Uttar Pradesh. The case study explores the impact that investments in maintaining a highway at low levels of rolling resistance might have on the overall lifetime emissions from the highways.

3.1.2 Construction and maintenance-related CO_2 emissions of the entire NH network

The project-level CO_2 emission estimates presented in section 3.1.1 provide an understanding of the emissions resulting from the different types and categories of highways in India. These estimates of emissions generated for different types of highway stretches were further used to derive the total construction and maintenance-related CO_2 emissions for the entire NH network using the methodology described in section 2.3.1.4.

The scaling up methodology required using the emission intensity/factors per lane km of construction and maintenance for different terrains (plains and hilly) determined for different highway stretches. The emissions factors used for construction and maintenance are provided in Table 18.[2] These factors were applied to the entire NH network to estimate the CF from construction and maintenance-related activities on Indian highways. Based on this methodology, it is estimated that the annualized emissions[3] resulting from the construction- and maintenance-related activities on the existing NH network on 2016 were 15 MT CO_2e.

Table 18: Emissions factors by highway type

Tonnes of CO_2 per lane km per year	Plains	Hilly
Construction	71.49	70.56
Maintenance	6.78	5.60
Total	**78.27**	**76.16**

Source: TERI Analysis

With a highway network, which is expanding every day, it is expected that the emissions as a result of construction and maintenance activities would also continue to rise. Keeping in line with the ministry's objective of adding 20 km of highways every day, it is expected that the NH network in the country would increase from 3.3 lakh lane km in 2016 to 5.69 lakh lane km in 2030 (TERI estimates) (Figure 14). If the construction and maintenance technologies and maintenance process regimes are assumed to remain the same during this period, this would lead to increased volumes of emissions on account of the highways in India.

Consequently, the annualized emissions from the construction and maintenance of the total NH network in India can be broadly estimated to grow to 30.5 MT CO_2e by 2030 (Figure 17).

This twofold increase in annualized emissions over the 15-year period can be reduced by taking adequate emissions mitigations measures. Several interventions are possible to reduce the rate of growth of such emissions emanating from the construction and maintenance phases of developing India's highways.

Measures, such as adoption of low-carbon materials which have low emissions factors, use of locally available materials reducing the need for transportation, and the use of low-energy construction techniques

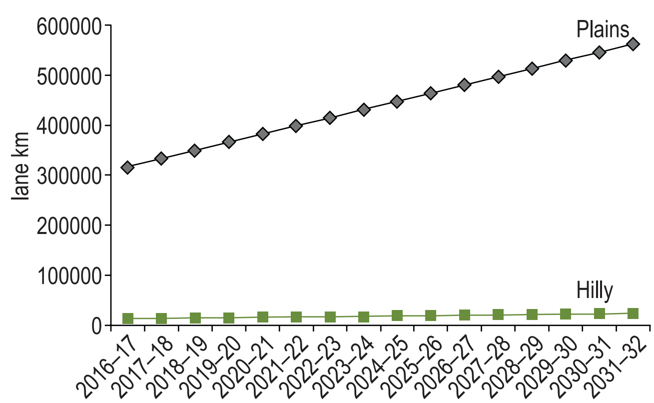


Figure 14: Trend in the growth of NHs network

[2] Emission factors for construction and maintenance have been calculated using the emission numbers reported for the representative NHs. The emission factors are obtained by dividing the total CO2 emissions per year by the total terrain-wise lane km of NHs.

[3] Annualized emissions are calculated by taking the total emissions occurring through the life of the highway, and apportioning the emissions by the number of years of its life.

could result in reduced emissions resulting from the construction and maintenance of highways in India.

The analysis in the subsequent chapter examines the potential impacts that the following four types of measures might have on the overall emissions from highways:

i. Reducing distances of material movement and promoting local sourcing
ii. Using larger vehicles for materials movement to increase fuel efficiency per tonne km moved
iii. Improved fuel efficiencies of vehicles used to move materials
iv. Reducing the periodicity of maintenance cycles while ensuring high-quality highways

3.2 CO_2 emissions from operations activities

Unlike the phases of construction and maintenance of highways, which are stationary sources of emissions, the emissions resulting due to the operations of vehicles on the highway stretches under consideration are more transient depending on the non-stationary vehicle traffic operating on the same.

As stated in the previous chapter, large variation in the volume, type, and nature of traffic across different types of highway sections makes it difficult to have an adequate number of representative highways which can be used to scale up to a national level-traffic estimate. In the absence of an adequate amount of data from across different representative highway sections, the current study relied on the estimates of traffic and energy consumption on NHs from NITI Aayog's IESS, in which TERI was also involved among other stakeholders. The contours of the model used to estimate the CO_2 emissions from vehicle operations on highways have been outlined earlier in section 2.3.2.

Based on the national estimates of traffic, of an estimated total of 8,195 billion passenger kilometres and 1,405 billion tonne kilometres of total traffic on Indian roads in 2016-17, 2,458 billion passenger kilometres (30%) and 702.5 billion tonne kilometres (50%) moved on National Highways alone. While there are different categories of vehicles which are plying on the National Highways, starting from passenger cars to heavy commercial vehicles (HCVs), the share of passenger traffic on buses, and freight traffic on HCVs appear to dominate the traffic volumes.

These traffic volumes translate into an estimated 105.12 MT CO_2e emissions from vehicle operations on NHs in 2016. This represents 41% of the total transport sector emissions (256 MT) of India in 2016, with the largest share of vehicular emissions on highways coming from HDVs, followed by bus and omnibus, LCVs, and cars (Figure 15).

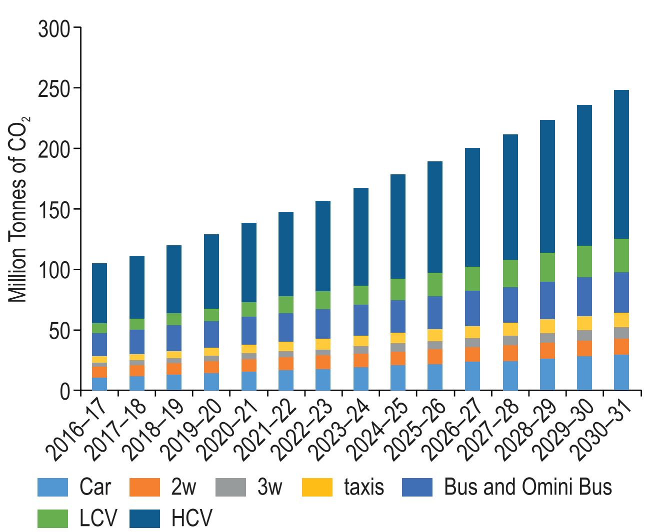


Figure 15: Category-wise CO2 emissions from NH-level operations

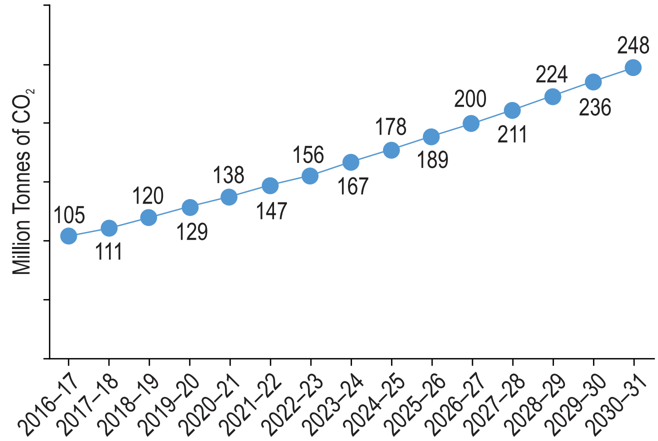


Figure 16: Growth trajectory of CO2 emissions from vehicular operations on –NHs: The BAU scenario

(Source: TERI Analysis)

On comparing the estimates of emissions from the construction and maintenance phases of the total NH network, the operations phase of emissions emerge to be significantly higher amounting to about 86% of the total emissions from the three phases.

Under the business-as-usual scenario, given India's robust economic growth trajectory, the demand for mobility on highways is expected to continue growing. Reflecting this growth, the energy consumption and CO_2 emissions resulting due to vehicular operations on highways would also continue to rise. It is estimated that the CO_2 emissions from vehicular operations on National Highways is expected to grow to 247.8 MT by 2030, an increase (CAGR) of 6.3% between 2016 and 2030. As of 2030, this will represent 37.5% of India's transport sector CO_2 emissions. The source of most of the emissions from vehicular traffic, even in 2030, will continue to be generated due to the operations of buses, omnibuses, and HCVs.

As discussed in Chapter 1, 'Introduction', given the vital role that the transport sector is going to play to help India meet its NDC targets for 2030, managing the vehicular emissions and mitigating them would be crucial. Specifically for the NHs, a large number of efforts could be taken up to reduce the operations-related vehicular CO_2 emissions.

The subsequent chapter, Chapter 4 'Reducing the Carbon Footprint of National Highways: Potential Interventions', highlights potential interventions and scenarios for emission mitigation from the operations phase. The emissions mitigations strategies considered as part of this study for the operations phase of the highways can be broadly classified as:

i. Reduced rolling resistance to increase operational efficiencies
ii. Improved vehicular fuel-efficiency levels
iii. Shifting to larger trucks to increase efficiency per tonne km moved
iv. Move to electric drivetrains to reduce emissions intensities
v. Increased public transport such as buses for passenger mobility

The potential reductions in CO_2 emissions on account of these interventions are discussed in the next chapter.

3.3 Total CO_2 emissions, India NHs: Summary

When combining the emissions resulting from the three different phases in the life of a highway, namely,

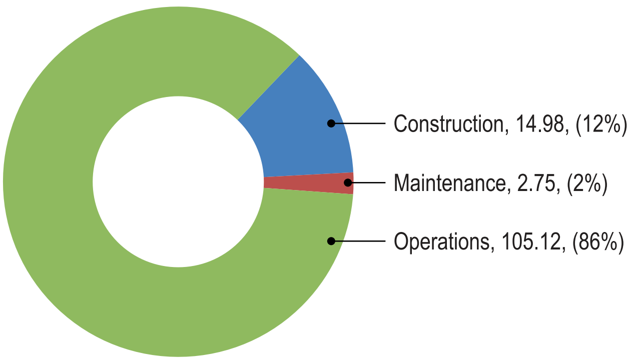


Figure 17: Emissions and share of construction, operations, and maintenance from India's NHs sector in 2016 (million tonnes, %)

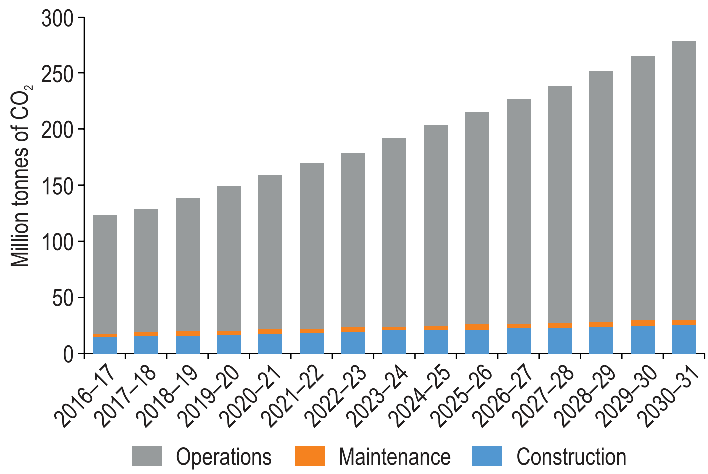


Figure 18: Growth in total CO2e emission (construction and maintenance) of NHs from 2016 to 2030

(Source: TERI Analysis)

construction and maintenance (periodic and annual), the study reveals that the operations phase of the highways results in the largest share of emissions from highways in India (~86%).

Figures 17 and 18 summarize the CO_2 emissions from the construction-, maintenance-, and operations-related activities on India's NHs. Of a total of 122.85 MT of annualized CO_2 emissions on account of the NHs network in 2016, operations of vehicles have the highest share (86%) of the sector's CO_2 emissions. As can also be seen in Figure 16, the construction and maintenance have a share of about 14% in total NH sector emissions in the same year.

Given the growth in the highway network and, consequently, the traffic on the highway system, the annualized CO_2 emissions from the highways are expected to increase to 278 MT by 2030 (Figures 18 and 19). Given this, 2.3 times growth in emissions expected from the highway sector over the next one and half decades, the need for carbon reduction from the NHs becomes a matter of utmost importance in order to meet India's commitment of reducing its CO_2 emissions. While this clearly indicates the need to focus on operations from the perspective of reducing CO_2 emissions, it is not to be derived that reducing the construction and maintenance emissions is not important. India also needs to focus on reducing its construction and maintenance emissions by adopting clean/low-carbon practices/technologies/materials. The potential interventions that can help reduce the overall CO_2 emissions from the NH sector have been discussed in the following chapter.

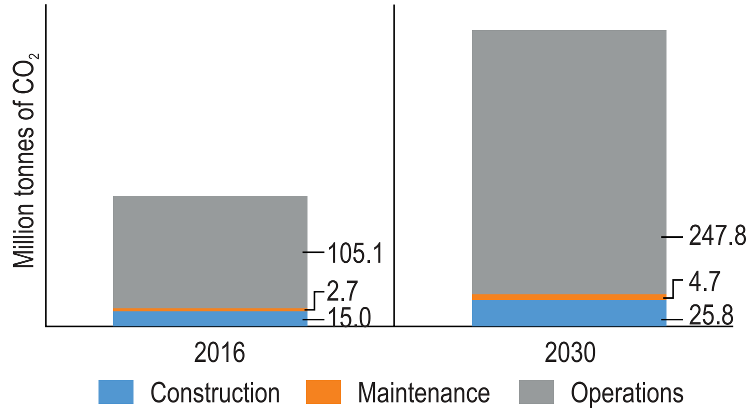


Figure 19: Summary of CO2 emissions on account of construction, operation, and maintenance of NHs in India during 2016 and 2030

(Source: TERI Analysis)

4 Reducing the Carbon Footprint of National Highways: Potential Interventions

4

Reducing the Carbon Footprint of National Highways: Potential Interventions

As highlighted in the previous chapter, carbon emissions in a highway's life occur on account of activities linked to its construction and maintenance and vehicular operations on it. In terms of shares, however, it is the operations of vehicles on highways that dominate the lifetime emissions with a share of nearly 86% in total lifetime emissions.

Given that road transport, and highways in particular, have a significant impact on the overall emissions profile of the country, it will be critical for India to reduce these emissions from highways in order to reduce the overall transport sector's CO_2 emissions and meet its NDC commitments. Interventions to reduce CO_2 emissions are not only possible at the time of construction and maintenance of the highways, but also during the operations phase if there is greater national coordination of policies and practices for reducing the same.

The following sections describe some of the possible initiatives that can be taken up to reduce such emissions and evaluates the same by drawing up alternate scenarios. The interventions that can help reduce CO_2 emissions from vehicular operations on NHs are discussed in the following section followed by the opportunities that exist for reducing the emissions from the construction and maintenance phases.

4.1 Reducing CO_2 emissions from vehicular operations: Potential interventions

The significantly high share of CO_2 emissions from the operations phase of highways necessitates exploration of strategies that would reduce the emissions from this phase. Given the large volume of traffic currently operating on highways, measures that could reduce the energy intensity levels of these modes would be instrumental in reducing the overall volumes of emissions from highways.

Some of the key interventions that might lead to reduced emissions during the operations phase of the highways could be as follows:

a. Increased share of energy efficient modes of transport

Shift of passenger and freight movement from road to rail transportation has a significant potential in terms of CO2 emissions savings. One of the key commitments of India, under the Intended Nationally Determined Commitment, is to increase the share of railways in country's total transport (UNFCCC, 2015). The future transportation strategy by the GoI should, therefore, focus on initiatives and projects to increase the share of environment friendly and energy efficient modes like railways and waterways.

It is estimated that an increase in rail share in passenger movement by 13% and in freight movement by 17%, can result in CO2 emissions reduction of about 12%. Table 19 gives the resultant emission reduction potential on account of increase in rail share and reduction in road share in moving passengers and freight.

b. Improved vehicular fuel efficiency levels

Increased fuel efficiency levels in vehicles result in lower energy consumption, which in turn results in lower CO_2 emissions. The GoI has already

Table 19: CO_2 emissions reduction on account of shift in passenger and freight movement from road to rail

	2016-17	2021-22	2026-27	2031-32	Emission reduction by 2031-32 (%)
Freight movement					-13%
% change in road share in TKM	-2%	-4%	-6%	-8%	
% change in rail share in TKM	3%	6%	10%	13%	
Passenger movement					
% change in road share in PKM	-1%	-1%	-2%	-2%	
% change in rail share in PKM	4%	9%	13%	17%	

TKM: Tonne km; PKM: Passenger km; Source: TERI Analysis, 2016

notified fuel efficiency standards for passenger cars (BEE, 2014) (BEE, 2015) and heavy-duty vehicles[1]. Implementation of these fuel efficiency norms has the potential to significantly improve the fuel efficiency levels of both passenger and commercial vehicle fleets (Sharma, Dutta, Sitalakshmi, Hiremath, & Sundar, 2013)[2] (ICCT, 2014). Estimates across some studies suggest that a whole package of energy efficiency measures could lead to as much as 35% emissions savings annually by 2030 (Karali, Gopal, Sharpe, Delgado, Bandivadekar, & Garg, 2017).[3] Implementation of these fuel efficiency norms would, therefore, lead to reductions in fuel consumption, energy use, and emissions from the operations phase during the life of the highways.

In the scenario where fuel efficiency norms formulated by the GoI lead to a 20% improvement in fuel efficiency levels for both cars and heavy-duty vehicles starting 2017 are estimated to result in reduction in annual highway emissions from traffic operations by about 13% in 2030. From an emissions level of 247.8 MT of CO_2e in 2030, occurring on account of vehicle operations alone, the emissions on highways can be reduced to 215.42 MT of CO_2e by making the vehicles plying on the highways 20% more fuel efficient.

c. Improve the inspection and maintenance (I&M) system for on-road vehicles

Poorly maintained vehicles are a major source of emissions from the transport sector. It is estimated that about 60% of vehicular pollution in India can be attributed to about 20% of poorly maintained vehicles or vehicles which are older than 10 years (TERI, 2014). With the rising number of vehicles on Indian roads, the number of old vehicles is expected to grow manifold as compared to that in the past.

Testing of emissions from in-use vehicles is carried out at pollution under control (PUC) centres, which are typically located at fuel filling stations. It is mandatory for vehicle owners/users to obtain PUC certificates periodically with the frequency of PUC checks typically varying between one to four times a year. In addition to PUC certification, commercial vehicles are also required to undergo fitness certification; no such requirement is there for non-commercial vehicles. However, the practice of scheduled maintenance of commercial vehicles is almost missing or, at best, taken up in the unorganized sector (ex-OEMs).

It is also now mandatory for all the diesel vehicles manufactured post-April 2013 to be installed with OBD (on-board diagnostic system). While OBD is not a part of formal PUC testing as of now, the vehicles manufactured in future will have higher dependence on electrical equipment making OBD all the more useful; more sophisticated versions of OBD are expected to be introduced in 2020 along with BS-VI vehicles (TERI, 2016). The government is also envisaging establishment of central inspection and certification centres, a couple of which have already come up at Burari and Nashik. A detailed study by TERI in 2016 has made recommendations, which have been discussed in section 4.4, for establishing a robust I&M regime.

d. Scrapping of old/end of life vehicles

Old/inefficient vehicles are also big source of carbon emissions, which should be phased out in a planned manner. An average life of a vehicle is around 10-15 years, but in India it largely depends upon the final owner of the vehicle. As per estimates, India had over 8.7 million end-of-life vehicles (ELVs) by 2015, which is likely to touch 21 million in 2025 (Akolkar et al. 2015).

In May 2016, MoRTH came out with a concept note on Voluntary Vehicle Fleet Modernization Programme to encourage vehicle owners to replace their old ones with the new ones. It is recommended

[1] https://beeindia.gov.in/sites/default/files/HDV%20Gazette%20Notification.pdf

[2] http://shaktifoundation.in/wp-content/uploads/2014/02/Developing-pathways-for-fuel-efficiency-improvements-in-HDV-sector-in-India.pdf

[3] https://ies.lbl.gov/sites/default/files/2017_india_hdv_report.pdf

that the programme should be implemented as early as possible and the replacement/scrapping of old vehicles be made mandatory instead of voluntary. When implemented, it will be a significant move towards sustainability as well as reduction in operation phase emissions. Currently, there are not many countries, except Japan, Korea, China, and European Union that have dedicated legislation for managing ELVs.

e. Reduced rolling resistance

Maintaining optimal rolling resistance on highways have multiple benefits, such as improved ride comfort, increased safety, lower vehicle wear and tear, and increased fuel efficiency and, therefore, reduced emissions. Such benefits and potential gains in fuel efficiency as a result of reduced rolling resistance are explained in greater detail in Chapter 5, 'Good-quality vs Bad-quality National Highways: Life cycle Emission Analysis'.

Some of the international studies highlight that an improvement in the rolling resistance (roughness index) by 53% could lead to gains in fuel efficiency of heavy vehicles, such as trucks and buses by as much as 2.5% (Dave Amos , 2006).

In a hypothetical scenario where periodic maintenance activities could be carried out across the entire NH network to ensure an optimal rolling resistance in the range of about 1.8–2 m/km, thereby increasing the fuel efficiency of all vehicles plying on the same by about 2.5%, it would have a small but significant impact on the overall emissions from the highways. When evaluated in terms of the total traffic operating on highways, the annual emissions resulting from the operations of vehicles on the entire highway network could be reduced by about 2% as of 2017 if all highways were simultaneously upgraded to this higher grade. To give a perspective on the benefits of even a relatively small savings, the Ministry of Petroleum and Natural Gas suggests that a reduction in 2% fuel consumption from vehicles in India could lead to as much as Rs 14,000 crore of savings for the country as of 2017 (PIB, 2017). Maintaining good quality of pavement would require good maintenance works using latest technologies. Specific recommendations with regard to maintenance technologies and maintenance funding have been discussed in section 4.2, followed by specific suggestions on policy interventions for improving maintenance works in section 4.4.

f. Shifting to larger trucks

Given that heavy-duty vehicles, and trucks in particular, appear to generate the highest share of traffic across Indian highways, a large potential exists to reduce the energy consumptions and emissions levels by making their operations efficient.

Currently, heavy-duty trucks are generally categorized into four different weight categories; these are as follows:

a. >7.5 but ≤12 tonnes

b. >12 but ≤16.2 tonnes

c. >16.2 but <=25 tonnes

d. > 25 tonnes

Studies suggest that the Indian truck fleet has historically been small in size and under-powered compared to the freight that it moves (Sharpe, 2015). Even today, India has one of the highest shares of small-size trucks (classified as freight vehicles greater than 7.5 tonnes) sales in the world.

However, there is a gradual transition that is currently being seen in the trucking industry in India with greater sales being recorded of high-capacity trucks (Figure 20). Moving freight on larger trucks, which have higher capacities, makes the operations significantly more efficient. They result in reducing the energy consumption and emissions resulting from the movement of one unit of freight across one unit of distance.

If measures, such as freight aggregation, logistics parks near urban and industrial centres, etc. could be encouraged to enable a transition to move greater shares of freight onto larger trucks, then this measure could also lead to reducing the emissions from trucks operating on highways.

In a scenario where 5% of the traffic currently being moved by every truck category (other than the >25 t category) are moved to the higher category of trucks as shown in Table 20, there will be potentially as much as 6% of emissions reduction from highway traffic/operations in 2030.

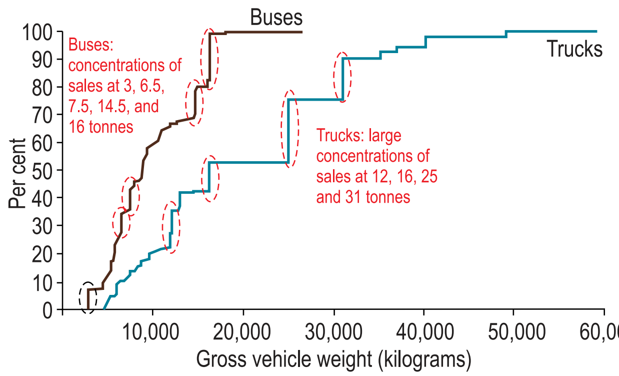


Figure 20 Current share of weight categories in heavy-duty vehicle sales in India in 2014 (Sharpe, 2015)

Table 20: Share of highway freight traffic on different truck weight categories

Truck type	7.5–12 t	12–16.2 t	16.2–25 t	> 25 t
BAU Share	11.99%	25.77%	45.38%	17.85%
ALT Share	6.80%	21.05%	40.04%	32.11%

Source: TERI Analysis

It is also recommended that for larger trucks, the engine size >9 litres is considered to keep an optimum engine-to-weight ratio. *Engines between 3 and 7 litres make up almost 99% of the total sales market* in India (Sharpe, 2015). The low engine-to-weight ratios in the Indian HDV segment leads to lower speeds of trucks. It is recommended that engine-based standards/ categorization should be developed depending on the use/purpose of HDVs.[4] For instance, if an HDV is used for heavy haulage (>25 t), then higher-engine-capacity (>9 litres) trucks should be preferably used/deployed.

g. Move to Electric Drivetrains/Alternate Fuels

Electric vehicles are inherently more energy efficient than internal combustion engines at the tailpipe. They also have the potential to be completely emissions free when the source of power generation is from renewables. A move to electric drivetrains for vehicles operating on highways could also be considered as one of the emissions mitigation strategies for reducing the emissions footprints of highways.

However, currently, India still uses coal-based thermal power plants for generating over 70% of its electricity. Considering a mode shift as shown in Table 21, at the current mix of coal in power generation, a move to electric drive-trains for passenger vehicles are seen to have an impact on the CO_2 emissions levels (to the tune of 4.7%) from highway operations by 2030.

Table 21: Share of electric vehicles in vehicle stock of different vehicle categories and operations phase emission reduction

	Car	2W	3W	Taxis	Bus	Operations phase emission reduction (2030)
BAU	1.51%	3.21%	2.90%	2.50%	0.38%	4.7%
ALT Scenario (Best case)	3.76%	8.21%	4.90%	4.75%	1.13%	

Source: TERI Analysis

Similarly, other low-carbon fuels should be adopted to lower the emissions from vehicular operations.

h. Increased share of public transport

Public transport such as buses, are significantly less emissions intensive than private vehicles such as cars. A possible shift of passenger mobility from cars to buses could also help mitigate CO2 emissions resulting in NHs in India. Efforts to increase the service quality, reliability, and safety of buses could potentially shift some of the existing passenger traffic from passenger cars to buses.

In the business-as-usual scenario, the share of passenger traffic (in terms of BPKM) moving on buses on Indian highways is expected to reduce from the current 2016 levels of 70% to about 63% by 2030. If efforts such as those mentioned above are undertaken to retain and marginally increase

Table 22: CO_2 emissions reduction on account of increase in public transportation share in total BPKM on NHs

Particular	Car	2w	3w	Taxi	Bus	Operations related emissions (MT CO2e)	% reduction
BPKM Share in 2030 (BAU)	13.81%	12.06%	5.49%	3.08%	65.57%	248	4%
BPKM share in 2030 (ALT)	11.24%	10.77%	4.84%	2.44%	70.70%	238	

BAU: Business-as-usual scenario; ALT: Alternate Scenario; Source: TERI Analysis, 2016

[4] http://www.theicct.org/sites/default/files/India%20HDV%20FE_webinar_11Aug2015_vfinal_for%20distribution.pdf

the share of passenger traffic on buses to a scenario of about 71%, CO2 emissions from the operations of highways could reduce by about 4% in 2030 as compare to the BAU.

As is evident from some of the scenarios considered above, the potential of reducing the emissions from highway operations is significant, and measures in that regard could significantly reduce the emissions from the overall lifetime of highway operations.

The following section explores the potential measures that can be taken up to reduce the emissions from highway construction and maintenance activities and their potential impacts on emissions.

4.2 Reducing CO_2 emissions from construction and maintenance: Potential interventions

While reducing emissions from traffic movement is critical and has largely been the focus of carbon mitigation strategies for the transport sector, there are several interventions that are possible and required to reduce the carbon footprint of construction and maintenance activities related to transport infrastructure creation and upkeep. This section lists and discusses the potential interventions for reducing the CF of construction and maintenance works in the NH sector. The interventions are drawn from international experiences and best practices and have been identified through the review of Indian guidelines, research papers, and journals (both Indian and international) as well as through discussions with concerned stakeholders, including contractors, consultants, and scientific research institutes. The listed interventions provide an array of options that could be experimented/ implemented by the authorities for reducing carbon emissions from the construction- and maintenance-related activities in the NH sector. The key potential low-carbon interventions discussed in this section are categorized into the following categories:

i. Green construction technologies
ii. Alternate materials
iii. Interventions during the planning and design stages
iv. Interventions during the pre-construction stage
v. Interventions during the construction stage
vi. Interventions during the maintenance stage

A few of the other interventions that have the potential to reduce carbon emissions from the construction- and maintenance-related activities in the NH sector are discussed in Annexure 4.

4.2.1 Green construction technologies

4.2.1.1 Warm-Mix Asphalt	
Warm-mix asphalt (WMA) presents a lesser energy-consuming alternative to the conventional hot-mix asphalt (HMA). It is produced at temperatures in the range of 20 °C to 40 °C, lower than a typical HMA; HMA is produced and mixed at temperatures between 150 °C–170 °C, whereas WMA is produced and mixed at temperatures roughly between 100 °C and 140 °C.	
Key advantages (Ankit Sharma et al., 2012)	» Since WMA uses less energy/heat, it reduces fuel requirements for the production of asphalt mix and results in lower CO_2 emissions as compared to HMA production. It, therefore, reduces the greenhouse gas emissions by 25–30 percentage per m^3. » This technology is compatible with recycled asphalt pavement (RAP). » Lower mixing temperature reduces the oxidation and aging of the bitumen, and, therefore, provides a longer life to the pavement as compared to hot-mix technology. » Reduced rate of cooling provides longer workability and permits longer haulage from plant to work sites.
Savings in cost	'WMA is most likely to have long term cost advantages, though its estimation should be case specific. The cost advantage is a trade-off between the additional cost of using the additives and technologies (including plant modification) and cost savings achieved through reduced fuel consumption, longer life of pavement and use of recycled material' (IRC: SP 101, 2014). The major difference in WMA and HMA is on account of the use of fuel to heat the bitumen. Fuel savings with WMA typically range from 20 to 30% per m^3 (Julide Oner *et al.,* 2015). Hence, the same savings by using lesser fuels can be translated as cost savings.

<table>
<tr><td>Savings in CO_2 emissions</td><td>» 20% to 40% reduction in CO_2 emissions from the plants used for the preparation of WMA carpet have been reported as compared to HMA (D'Angelo et al., 2001).

» In India, WMA was experimented by the Central Road Research Institute (CRRI), New Delhi, for the construction of the 62 km Jodhpur–Pali section of NH-62 in Rajasthan,[5] and it was seen that this technology reduces GHG emissions to the tune of 32 gm CO_2 equivalent per m2 area compared to HMA. 'For the total project 590 tonne of CO_2 emissions were saved' (Siksha Kar et al., 2015).</td></tr>
<tr><td>Status of use</td><td>WMA is already being used in USA and some European countries. In India, the use of WMA technology is gearing up; a number of research works have been carried out to make the technology adoptable for the Indian climatic conditions. Indian road contractors are accepting this technology and using it in the construction of highways.</td></tr>
<tr><td>Recommendation in Indian guidelines</td><td>In 2015, Indian Roads Congress (IRC) published the WMA guidelines (IRC: SP 101-2014) to promote the adoption of the WMA technology for road construction. At present, there are more than 30 different WMA technologies, using patented processes and products, which have the potential of bringing reduction in mixing, laydown, and compaction temperatures of bituminous mixes (IRC: SP 101, 2014). IRC 101 gives a brief description of the following types of WMA technologies/processes :

» Foaming
» Chemical additives
» Rheological modifiers
» Hybrid technologies</td></tr>
<tr><td>Indian examples</td><td>
<table>
<tr><th colspan="4">Table 23: Road stretches/projects known to have used WMA</th></tr>
<tr><th>Name of the road</th><th>State</th><th>Type</th><th>Length (km)</th></tr>
<tr><td>Bawana Industrial area</td><td>Delhi</td><td>Arterial Road</td><td>0.5</td></tr>
<tr><td>Godhra–Halol section of SH-5</td><td>Gujarat</td><td>SH</td><td>11.0</td></tr>
<tr><td>Jodhpur–Pali road (NH-62)*</td><td>Rajasthan</td><td>NH</td><td>N.A</td></tr>
</table>
* Pilot Study; Source: (Rajiv Kumar and Satish Chandra, 2016)</td></tr>
<tr><td>Recommendation</td><td>Use of warm-mix technology in the construction of highways should be promoted in the construction of the NH sector as it offers advantages of energy savings and CO_2 reductions over the full life of the highway.</td></tr>
<tr><td colspan="2">4.2.1.2 Cold-Mix Asphalt</td></tr>
<tr><td colspan="2">Cold mix is a bituminous mixture containing unheated mineral aggregate, water, and binder (bitumen emulsion) prepared by a suitable device like a concrete mixer or cold-mix plant or a modified hot-mix plant.</td></tr>
<tr><td>Key advantages</td><td>The key advantages of cold-mix asphalt are as follows:[6]

» The technology reduces the energy requirement during constructions as it does not need additional heating nor does it require petroleum solvent to make it workable.

» It reduces local pollution as on-site burning of fuels is not required to prepare bituminous mix.

» Bitumen emulsions have the ability to coat damp aggregate surface, which eventually reduces the fuel requirements for heating and drying aggregates.

» Availability of various kinds of emulsions has led to development of new formulations, which satisfy certain design and construction requirements and help encourage the use of local available materials.</td></tr>
<tr><td>Savings in cost</td><td>'(Dr. P.K Jain, 2011)' suggests that the construction of 1 km of rural road using HMA is cheaper by 5% as compared to cold-mix construction.</td></tr>
</table>

[5] https://www.omicsgroup.org/journals/estimation-of-carbon-footprints-of-bituminous-road-construction-process-2165-784X-1000198.pdf

[6] IRC SP: 100, 2014

<table>
<tr><td>Savings in CO_2 emissions</td><td>For the construction of rural roads in India, it was seen that the cold-mix technology is 90% energy efficient, saving 1,500 litres of fuel per km of construction, which is equivalent to 4,000 kg of CO_2 emissions per km.[7] (This is in In the context of Indian rural roads.)</td></tr>
<tr><td>Status of use</td><td>‘In India, bitumen emulsion found its use only in the 1970s. The entire world used 12 million tonnes of emulsion during mid-1970s, India consumed only 20,000 tonnes till 1996, out of the total bitumen consumption of about 2 million tonnes. However, there has now been a steady rise in the use of bitumen emulsion recently and significant growth in demand of emulsion has been observed after 2005’ (IRC: SP-100, 2014). About 4,000 km of rural roads have been constructed with cold-mix technology in the states of Assam, Tripura, Meghalaya, Maharashtra, Karnataka, West Bengal, and Himachal Pradesh in the last 5–6 years (CSIR-CRRI and BITCHEM, 2013). There is a need to do more research on cold-mix technology so that it can be used for the construction of NHs as, presently, it is primarily being used for rural and urban roads with low-volume traffic.</td></tr>
<tr><td>Recommendation in Indian guidelines</td><td>The IRC has published the Code IRC: SP 100-2014 for providing methodology and specifications for the use of cold-mix technology for the construction of rural roads. This code specifies the details of the following applications/processes:
» Spray applications
» Surface treatments
» Cold mixes
» Half-warm mixes
» Maintenance mixtures using bitumen emulsion
» Cold recycling using bitumen emulsion</td></tr>
<tr><td>Indian examples</td><td>Apart from nearly 4,000 km of rural roads that are constructed using cold-mix technology, the following NH stretches/projects are known to have used cold-mix asphalt
<table>
<tr><th colspan="4">Table 24: NH stretches/projects known to have used cold-mix asphalt</th></tr>
<tr><th>Name of the road</th><th>State</th><th>Type</th><th>Length (km)</th></tr>
<tr><td>Jammu–Srinagar Highway NH-1A near Patnitop*</td><td>Jammu & Kashmir</td><td>National Highway</td><td>0.4</td></tr>
<tr><td>Jowai–Badarpur Road NH-44 near Silchar*</td><td>Assam</td><td>National Highway</td><td>N.A</td></tr>
<tr><td>H–S Road near Hanumangarh*</td><td>Rajasthan</td><td>National Highway</td><td>N.A</td></tr>
</table>
*Field trial; Source: (Dr. N.K.S Pundhir, 2006), (http://www.i-cema.in/past_event/P.K.Jain.pdf)</td></tr>
<tr><td>Recommendation</td><td>Cold-mix technology is extensively being used in the construction of rural roads. It is recommended that the use of cold-mix technology for NHs should be piloted/experimented to understand its feasibility and performance.</td></tr>
</table>

4.2.1.3 Soil stabilization

‘Soil stabilization improves the soil strength and it also increases the resistance of soil to the softening by water. This is done by bonding the soil particles together, water proofing the particles or combination of the two’ (TRB, State of the art review, 1993). The methods used for soil stabilization fall into two broad categories, namely, mechanical stabilization and chemical stabilization.

Mechanical stabilization: In this method, the physical nature of soil particles is altered by inducing vibration or compaction or by incorporating other physical properties, such as barriers and nailing (Makusa, Gregory Paul, 2012).

Chemical stabilization: In this method, the desired effect is achieved through the means of chemical reaction between stabilizer or the cementitious material and the soil particles (Sridevi, 2016). Cementitious materials used for stabilization are: cement, lime, fly ash, bitumen, or a combination of these and commercially available stabilizers.

[7] http://bitchem.com/why-us/advantages-of-coldmix/; last accessed on May 2, 2017

Key advantages	The key advantages of soil-stabilization are as follows:[8] » Utilization of local and in situ materials » Large number of waste materials can be utilized by increasing their strength » Large savings in aggregate consumption » Since locally available materials can be used and aggregate consumption is less, there can be savings in consumption and reductions in CO_2 emissions on account of transportation of material.
Savings in cost	An experimental case study was done on the rural road Kali-Mahudi section in the district of Dahod, Gujarat. Cost reduction of Rs 12,342 per km, equivalent to about 1% reduction in cost per km, was observed in the stretch constructed using chemical soil stabilisation as compared to the stretch without having any type of soil stabilisation (Ujjwal J Solanki et al., 2009).
Savings in CO_2 emissions	The MoRTH issued a circular regarding the usage of alternative and new technologies for the construction of NHs.[9] In consonance with this circular, Uttar Pradesh PWD attempted few road projects using soil stabilization technology. One such project titled 'Strengthening and Widening of the Sikandra–Jhinjhak–Rasulabad MDR (KM-21-40)' used cement stabilization. It was reported that for a 20 km stretch, 2 lakh tonnes of coarse aggregate was saved by using this technology.[10] This savings in coarse aggregate led to 18,000 lesser dumper trips to transport the aggregate which is equivalent to saving 12 lakh litres of diesel. This saving in the consumption of aggregate and diesel converted into savings of about 24.52 tonnes of CO_2 per km (fuel savings and emission reduction calculations done by TERI).
Status of use	*'The modern era of soil stabilisation began during the 1960's and 70's when general shortages of aggregates and fuel resources forced engineers to consider alternatives to the conventional techniques of replacing poor soils at building sites with shipped-in aggregates that possessed more favourable engineering characteristics.'*[11] At present, Japan,[12] Europe,[13] and USA[14] are using soil stabilization to improve the properties of the soil. In India, the use of soil stabilization is gearing up and it is being used in the construction of various highways.
Recommendations in Indian guidelines	The IRC has published several codes and specifications regarding soil stabilization technology, such as IRC: 028 and IRC: SP 89-2010. The MoRTH has also provided specifications of materials regarding chemical soil stabilization in its Highway Manual.
Indian examples	(see Table 25 below)
Recommendation	It is recommended that the use of soil stabilization in the construction of highways should be enhanced. While there are several codes/specifications related to the use of soil stabilization technique/s, more research and awareness amongst concerned stakeholders is required to push the use of this technique in highway construction.

Table 25: Few road stretches/projects known to have used soil stabilization

Name of the road	Type	Length (km)
Ahmedabad–Udaipur (NH-8)	NH	260.0
Ahmedabad–Vadodara expressway	Expressway	93.1
Achad–Manor	NH	61.0
Sikandra–Jhinjhak–Rasulabad (km-21- km 40)	MDR	21.0

Source: IRC: SP 37-2012

8 IRC SP: 100, 2014

9 http://www.roadstab.com/images/Circular_on_New_materials_techniques_by_MORTH.pdf

10 KABA Infratech Private Limited

11 http://www.trstabilisation.co.uk/History-of-Soil-Stabilisation.html; last accessed on May 2, 2017

12 http://www.apdpmoldova.ro/wp-content/uploads/2010/07/New-soil-treatment-methods-in-Japan-by-H.-MichiJ.IwabuchiS.Chida_.pdf

13 http://www.eupave.eu/documents/activity-areas/soil-improvement-and-stabilisation.xml?lang=en; last accessed on February 17, 2017

14 https://www.nap.edu/read/22999/chapter/8

4.2.2 Alternate materials

4.2.2.1 Reclaimed Asphalt Pavement

'Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. These materials are obtained when asphalt pavements are removed for reconstruction, resurfacing' (Javed, 1992). After removing the asphalt pavement, it is processed in a central plant or at a site where the material undergoes a series of treatments including crushing, screening, conveying, and stacking. Properly processed RAP consists of high-quality aggregates that can be used as a base course bituminous layer.

Key advantages	There are three main environmental advantages of using RAP (Ning Lee et al, 2011) » Savings by virtue of not using virgin or natural aggregates » Reducing the accumulation of milled asphalt concrete, and hence decreasing the environmental impact due to disposal at landfills » Savings in on-site energy consumption as RAP requires lower temperature, about 135 °C, to dry as compared to the temperature required to dry the virgin aggregates (140 °C to 170 °C)
Savings in cost	Approximately 14%–34% (Burt Andreen et al., 2011) cost savings per tonne can be achieved by using RAP in HMA, depending on the percentage blending of virgin aggregates with the RAP.
Savings in CO_2 emissions	When the HMA mixture contains 30% of RAP by weight, it approximately saves 16% of energy and 20% of CO_2 per tonne, as compared to the HMA mixture produced using the virgin aggregates (Ning Lee et al, 2011).
Status of use	The use of RAP in pavement construction is very popular in USA,[15] Europe,[16] and China.[17] Nowadays its use is becoming prominent in India. Due to the environmental advantages offered by RAP, the government road agencies are encouraging contractors to use RAP wherever it is feasible to conserve natural aggregates (IRC: SP 101, 2014).
Recommendation in Indian guidelines	IRC has published a code IRC: 120-2015, which gives specifications for recycling of bituminous pavement materials for use as RAP. These guidelines are framed to cover the following five aspects of recycling: » Reclamation (hot and cold processes) » Hot in-place recycling (HIR) » Cold in-place recycling (CIR) » Hot in-plant recycling (HIP) » Cold in-plant recycling (CIP)
Indian examples	See Table 26 below

Table 26: Following road stretches/projects known to have used RAP[18]

Name of the road	State	Type	Length (km)
Chennai Tada NH-5 section	Tamil Nadu	NH	12
Vadodara–Halol section Phase 1	Gujarat	NH	11
Vadodara–Halol section Phase 2	Gujarat	NH	6
Ahmedabad–Mehsana section	Gujarat	NH	6
Mehrauli–Badarpur	Delhi	Arterial Road	14

Source: IRC: 120-2015

[15] https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11021/11021.pdf

[16] https://international.fhwa.dot.gov/pdfs/recycolor.pdf

[17] http://www.trb.org/Publications/Blurbs/171575.aspx

[18] IRC 37-2012 code Annex-XI

Recommendation	It is recommended that awareness should be created among various stakeholders regarding the benefits of the use of RAP. Incentives can be given in order to encourage/promote its use.

4.2.2.2 Geo-Synthetics

'Geo-synthetics are synthetic products, where at least one of the components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three dimensional structure, non-woven, knitted, or woven which is used in contact with soil/rock and/or other materials in geotechnical and civil engineering applications (M.S Verma, 2014).

Key advantages	The key advantages of geo-synthetics are as follows:[19] » Geo-synthetics in road construction can help reduce the requirement of excavating and transporting the good soil and can help increase pavement life, which can indirectly reduce the CO_2 emissions from road construction. » Use of geo-synthetics can result in increased service life of flexible pavement (Shih-Hsien Yang , 2006). » Increase the allowable bearing capacity by 40%–50%. » Increase the speed of construction due to quick installation and increase the possibility of construction to be completed in a shorter period.
Savings in cost	According to an estimate done by Geo-synthetic Material Association (USA), savings of up to $3.90 per square yard *(Rs 298 per square metre at the current rate-May 2017) have been achieved for the construction of new roads, using geo-synthetics as compared to a road constructed without geo-synthetics.*[20]
Savings in CO_2 emission	The GHG emission for a 1 km long road without using geo-synthetics is 730 tCO_2e; and 650 tCO_2e for a road that is constructed using geo-synthetics (Matthias Stucki et al., 2011).
Status of use	During the last decade, there has been an increase in the use of geo-textiles for road construction in North America. *'The Indian engineers are still getting acquainted with the use of geo-textiles* (G Venkatappa Rao et al., 2013).
Recommendation in Indian guidelines	IRC has published a code - IRC 113 - Guidelines for the Design and Construction of Geo-synthetic Reinforced Embankments on Soft Subsoils, and the MoRTH has published specifications in the highway manual which describe the specifications of aspects related to the construction and design of geo-synthetic reinforced embankment.
Indian examples	(see Table 27 below)
Recommendation	Given the advantages of geo-synthetics, it is recommended that the use of geo-synthetics in the construction of highways should be encouraged/promoted in the NH sector in India.

Table 27: Few road stretches/projects known to have used geo-synthetics

Name of the road	State	Type
Aligarh–Ghaziabad, NH-91	Uttar Pradesh	NH
Rehabilitation of heavy traffic road through Karnataka forests (Uttar Kannada, SH-30)	Karnataka	State Highway
Four-laning of the Nagpur–Hyderabad section of NH-7 from km: 123.00 to 153.00	-	NH
Meerut–Muzaffarnagar (km 52.25 to km 131.00)	Uttar Pradesh	NH
Karimganj–Tripura border section of NH-8 (new)	Assam	NH

Source: Techfab India[21] and Strata Geosystem (India) Pvt Ltd[22]

[19] IRC SP: 100, 2014

[20] http://services.dlas.virginia.gov/User_db/frmView.aspx?ViewId=3576&s=22; last accessed on April 17, 2017

[21] http://www.iahe.org.in/3.7%20Tech%20grid%20for%20reinforced%20earth,%20soil%20retaining%20wall.pdf

[22] http://www.strataindia.com/strataweb.html; last accessed on April 17, 2017

4.2.2.3 Plastic Waste

There are two methods for blending plastic waste in bituminous concrete for road construction. The first is the dry process in which the aggregates are heated to 170 °C in the hot-mix plant and the shredded plastic waste is added. The plastic gets coated over the aggregate uniformly after which hot bitumen at 160 °C is added and the road is paved using this mixture. The second process is the wet process where shredded waste plastics are directly mixed with hot bitumen at 160 °C (Parth H. Sadadiwala and Prof. Purvi P. Patel, 2015). Since the wet process requires a lot of investment and bigger plants, this process is generally not used.

Key advantages	The following are the key advantages of the use of plastic waste in bitumen mixes:[23] » It increases the resistance to deformation. » Plastic provides higher resistance to water-induced damages. » It increases durability and enhances fatigue life. » It provides improved stability and strength. » It addresses the issue of disposal of waste plastic, thereby making the use of plastic environment friendly.
Savings in cost	For constructing a 1 km road in Maharashtra, a total savings of Rs 16,206 was reported as compared to conventional roads. (Sandeep R Unde et al, 2015)
Savings in CO_2 emission	For the same road construction (mentioned above), 3.5 tonnes of savings in carbon credit was achieved on account of avoiding the burning of plastics wastes (Sandeep R Unde et al, 2015).
Status of use	*'Commercially made polymer-modified asphalts first became popular in the 1970s in Europe. Now, North America claims 35% of the global market.'*[24] At present, many states, such as Maharashtra, Madhya Pradesh, Karnataka, and Haryana are using plastic waste to make low-traffic volume roads.
Recommendation in Indian guidelines	*'In order to encourage the use of plastic waste, MoRTH has decided that bituminous mix with plastic waste shall be the default mode for periodic renewal of highways falling within the 50 km periphery of an urban area, having population of more than 5 lakhs. Any relaxation on ground of non-availability of plastic waste, cost, etc. shall involve approval of MoRTH. It has also been decided that a stretch of at least 10 km in each State/UT will selected for use of waste plastic on pilot basis so as to make it compulsory in contracts.'* (MoRTH, 2017)[25] IRC: SP 98-2013 gives the guidelines for the use of waste plastic in hot bituminous mixes in wearing courses.
Indian examples	The following road stretches/projects are known to have used plastic waste:[26] A 25 km road was laid using waste plastic in Bengaluru in 2001. The road showed superior smoothness, uniformity, and less rutting as compared to a road laid with conventional bituminous mix at the same time which began developing 'crocodile cracks' after some time. In Tamil Nadu, roads in various stretches were constructed using waste plastic as an additive in bituminous mix under the scheme '1,000 km Plastic Tar Road'. It was found that the performance of all the road stretches was satisfactory.
Recommendation	Plastic waste is currently being used for the construction of low-volume roads.[27] It is recommended that awareness measures should be undertaken to increase the deployment of this technique during the maintenance and construction of NHs.

23 IRC SP: 100, 2014

24 https://www.theguardian.com/sustainable-business/2016/jun/30/plastic-road-india-tar-plastic-transport-environment-pollution-waste; May 2, 2017

25 Available under circular and annexures on the ministries website (www.MoRTH.nic.in), Date: November 9, 2015, circular no : 33044/24/2015-S&R (R)

26 IRC:SP 98-2013

27 http://pmgsy.nic.in/WM_RR.pdf

4.2.2.4 Rubber Waste	
The environmental hazards related to the disposal of waste materials of the tyre industry are a big concern. The primary use of scrap tyre in road construction occurs as an additive in asphalt. This rubber is generally granulated and referred as crumb rubber modifier (Prof. Newman et al., 2012). Rubber when added to asphalt increases its durability and workability, hence improves the pavement quality and safety conditions by absorbing the rubber elastic properties.	
Key advantages	Advantages of the use of rubber waste in bitumen are as follows:[28] » Bitumen modified with crumb rubber (waste tyre) gives better resistance to fatigue and stripping improves the elastic modulus and increases the load-carrying capacity of the pavement. » It delays oxidation of the mix, thereby enhancing the pavement life.[29] » It addresses the environmental concerns related to the discarded tyres of automobiles. » Using modified bitumen mix can increase the life of pavements, which in turn reduces the maintenance requirements and demand of natural aggregates and other construction materials, thereby reducing the CO_2 emissions from pavement construction.
Savings in cost	According to estimates (study done in the USA), savings of $5 per tonne (Rs 32 2 per tonne) were seen in the case of modified rubber bitumen as compared to conventional hot-mix asphalt (Andrew Moss, 2016). The MoRTH also recommends the use of rubber modified bitumen as a binder in semi-dense bituminous concrete /bituminous concrete for routine and periodic maintenance of roads.[30]
Savings in CO_2 emission	For road constructed in California and Arizona, 100–223 metric tonnes of CO_2 per lane km were saved due to the use crumb rubber asphalt (Jorge Sousa et al, 2016).
Status of use	Modified crumb rubber is being used in various countries, such as USA, South American nations, and Malaysia.[31] In India, the concept of usage of waste tyre/crumb rubber for the roads took off in the year 1996.
Recommendation in Indian guidelines	IRC: SP 53-1999, which was revised again in 2010, gives some specifications regarding the use of crumb rubber bitumen. There is also an IS Code (IS 15462: 2004) for the specification of polymer and rubber-modified bitumen.
Indian examples	See Table 28 below
Recommendation	Even though there is an IRC guideline that gives the specifications for the use of crumb rubber bitumen, this technology has not yet gained pace/wider acceptance in India. Given the benefits of rubber waste (crumb rubber) in bitumen, it is recommended that its use should be encouraged and awareness among various stakeholders regarding its benefits should be created.

Table 28: Road stretches/projects known to have used rubber waste[32]

Name of the road	State	Type	Length (km)
Guwahati to Nalbari (NH-31)	Assam	NH	54.81
Silchar–Udarband (NH-54)	Assam	NH	25.87
Mundka–Lok Nayakpur	Delhi	Urban Arterial Road	4.00

Source: Industry reports

[28] http://amap.ctcandassociates.com/wp/wp-content/uploads/crumb-rubber.pdf
[29] http://ooms.nl/global/civiel/_ooms/afbeeldingen/research%20development/adb_rvr_tehran_2004.pdf
[30] Circular no :RW/NH-33044/10/2000-S&r; Date: September 26, 2002
[31] https://www.hindwai.com
[32] NHAI, DDA

4.2.3 Interventions during the planning and design stage

4.2.3.1 Geometric Design

Environment-friendly highway geometric design is emerging as one of the strategies to reduce the adverse impacts of fuel consumption and GHG emissions due to vehicle operations. The following interventions can be adopted to make highway geometric design environment-friendly (Myung-Hoon Ko, 2011).

1. Designing the vertical grade with higher initial speed with vertical grade less than 6%.

Key advantage	Low grade of slope reduces emissions from vehicle operation. (Myung-Hoon Ko, 2011)
Savings in CO_2 emission	According to a study done in Texas, upto 15% reduction in CO_2 emissions per trip was estimated during highway operation as compared to conventional highway design (Myung-Hoon Ko, 2011).

2. Designing vertical curve higher K-values.

Key advantage	Vertical curves with higher K-value results in smoother and gentle vertical curves, which in turn reduces the emissions from vehicle operations.
Savings in CO_2 emission	According to a study done in Texas, upto 10% reduction in CO_2 emissions per trip was estimated due to lesser use of fuel during highway operations as compared to conventional highway design.
Recommendation	Further research is required to evaluate the feasibility of the above-mentioned interventions for the construction of Indian highways.

4.2.3.2 Alignment selection: Use of LiDAR

LiDAR (Light Detection and Ranging) is a type of remote-sensing technology that helps to produce high-accuracy data for planning and design work. '*LiDAR is particularly effective in hilly, dense vegetation or a remote area as it is one of the survey techniques that can accurately measure ground levels directly. LiDAR uses a combination of three technologies namely rugged compact laser rangefinders (LiDAR), highly accurate inertial reference systems (INS) and the global Positioning satellite system (GPS). In a highway project it helps to produce timely, cost effective, environmentally friendly, reliable and accurate data for use in producing the pertinent highway drawings* (WANGARI, 2011).

Key advantages	The key advantages of LiDAR are as follows:33 » It has a vertical accuracy of 5–15 cm and horizontal accuracy of 30–50 cm » It helps in fast data acquisition and processing. » It reduces human dependence for surveying. » LiDAR pulses can reach beneath the canopy, making it ideal for mapping inaccessible and featureless areas.
Savings in cost	For the construction of 46 mile-long road in Texas, savings of Rs 96 million was observed as compared to conventional photogrammetric methods (Reginald Souleyrette *et al.*, 2002).
Savings in time	For a 100 km highway stretch in India, the conventional method of survey work is expected to take around 12 months as compared to 1.5 months (approximately) when LIDAR technology is deployed.
Status of use	Use of LiDAR technology has gained pace in USA, but it is still in the initial stages in India. '*Value addition works on four lane Lakhanpur-Vijaypur section from km 16.35 to km 80.00 of NH-44 (old NH -1A) in the state of Jammu and Kashmir*' is a project where it is proposed to use LiDAR technology.[34] A pilot project using LiDAR technology has also been done for the Konark–Kakatpur section of road in Odisha.[35]

33 http://home.iitk.ac.in/~blohani/LiDAR_Tutorial/AdvantagesofLiDARtechnology.htm
34 http://www.nhai.org/Doc/9mar17/RFP44.pdf
35 http://www.nhai.org/Doc/1apr16/LiDAR.pdf

Recommendation in Indian guidelines	There are no guidelines in India related to the use of LiDAR technology. Meanwhile, NHAI has approved the use of LiDAR technology as part of the model request for proposal (RFP) document.[36]
Recommendation	LiDAR technology is not only accurate but also cost effective and fast. It is, therefore, recommended that the use of LiDAR technology is encouraged and awareness regarding the benefits of its use are created among various stakeholders.

4.2.4 Interventions during pre-construction stage

Setting up site office and labour camp: Use of pre-fabricated structures	
The construction process of roads involves activities which are beyond mining, hauling, and laying material. These activities involve setting up temporary establishments, such as labour colonies, staff residences, and site offices. These activities also generate direct and indirect carbon emissions. On the construction site for offices and camps, some building elements can be assembled off-site and in a factory. These include pre-cast concrete floors and pre-assembled external walls.	
Key advantages:	The key advantages associated with the use of pre-fabricated site offices are as follows:[37] » Use of pre-fabricated site offices result in waste reduction and improved waste management as products are manufactured and assembled in a more controlled environment » Easy relocation and reuse for a different site location » Efficient use of scarce space available at the construction site
Savings in cost	In India, the cost of a single room accommodation that has a pre-fab structure is around Rs 11,305 per sqm.[38] As mentioned earlier, the pre-fab structures are reusable and are easy to transport hence reducing the cost of construction of new offices at a different site location.
Savings in CO_2 emissions	Since portakabin can be reused for more than one construction sites, up to 67% CO_2 is emitted in the production of a modular building than a traditionally constructed one.[39]
Status of use	Pre-fabricated portable offices/cabins are used in India as construction site offices.
Indian examples	Following road stretches/projects are known to have used pre-fabricated portable offices/ cabins: Pre-fabricated Porta cabins at New Toll Plaza at km 88.500 on NH-24 in the state of Uttar Pradesh.[40] Erection of pre-fabricated portable cabins at proposed Toll Plaza at km 121.975 of NH-24 in the state of Uttar Pradesh.[41] Installation of pre-fab Porta cabins, administrative office for Temporary Toll Plaza at km 584/500 of NH-7 in Allonia village, Seoni, Madhya Pradesh[42]. Temporary toll plaza (2 + 2 lane) at km 98.640 (near Naruar village) from km 69.500 to km 148.550 section of NH-57, district Madhubani, Bihar.[43]
Recommendation	Pre-fabricated portable offices/cabins are reusable and easy to transport, they are cost effective and have the potential to reduce the carbon emissions. Hence, it is recommended that the use of pre-fabricated offices/cabins should be encouraged.

[36] http://www.nhai.org/Circular.pdf

[37] http://ooms.nl/global/civiel/_ooms/afbeeldingen/research%20development/adb_rvr_tehran_2004.pdf

[38] Circular no :RW/NH-33044/10/2000-S&r; Date: September 26, 2002

[39] https://www.hindwai.com

[40] NHAI, DDA

[41] http://www.nhai.org/whatnewmar.asp; last accessed on June 27, 2017

[42] http://www.nhai.org/Doc/27jul11/NHAI%20PIU%20Narsinghpur%20Porta%20Cabin%20bid%20document%20Nh-7.pdf

[43] http://www.nhai.org/Doc/26July13/NITCUMTENDERDOCUMENT.pdf

4.2.5 Interventions during construction stage

4.2.5.1 Road construction machinery and equipment

Due to advancement in construction technologies, road equipment and machinery are increasingly being used for construction and maintenance/repairing works. These off-road machines can vary from handheld carts to heavy-duty bulldozers or tandem wheel rollers. Use of these machinery/equipment results in CO_2 emissions from the internal combustion of liquid or gaseous fuels or in case of equipment powered by electricity, due to off-site generation of electricity. The practices, which can be followed to reduce CO_2 emissions from the use of off-road machinery/equipment are discussed below.

1. Efficient use of machinery and equipment

Contractors should train the equipment operators to use the equipment more efficiently.

Reduction in CO_2 emissions:	*'Operator training programs can reduce fuel consumption by 5 percent or more per excavator cycle',* hence reducing CO_2 emissions (Stewart, 2003).
Status of use	After talking to various stakeholders/contractors it was found that no such training is given to the operators in India.
Recommendation	Proper training should be given to equipment operators in order to improve the efficiency of the equipment and reduce the CO_2 emissions.

Appropriate maintenance of machinery/equipment can improve the fuel efficiency. Proper maintenance of the machinery/equipment is also important to reduce engine wear and tear to improve the fuel efficiency of the equipment; changing oil and oil filters regularly keeps engine parts lubricated, thereby improving fuel economy and reducing engine wear.

Reduction in CO_2 emissions:	*'Fuel economy improvements of 2 to 3 percent due to improved oil filters have been recorded in highway tests'* (ICF International, 2010).
Recommendation	It is recommended that various operators should adopt practices of properly maintaining the construction machinery and equipment. Training programmes regarding the same can be imparted to technical personnel handing the equipment and machinery.

2. Machinery and equipment with advanced equipment technology and fuels

Using low-carbon fuels can help reduce CO_2 emissions from use of construction equipment. Most off-road construction equipment use diesel or petrol while, some of them also use engines fired by alternative fuels like LPG and CNG. Alternate/advanced technologies like hybrid energies can be considered while procuring new construction equipment. Hybrid diesel-electric equipment, which have been introduced recently for larger equipment like bulldozers and tractors offer significant fuel savings.

Reduction in CO_2 emissions	*'A 25 percent improvement in fuel economy can reasonably be expected from diesel hybrid models of excavators. Some manufacturers predict up to a 35 percent improvement in fuel economy'* (ICF International, 2010).
Status of use	After talking to various stakeholders/contractors it was found that these technologies are in the prototype/testing stage in India and in other countries, such as UK, France, USA, etc.
Recommendation	Further studies should be done regarding the use of hybrid electric vehicles for Indian conditions. Increase in cost and fuel/emissions savings should be estimated to understand the cost implications in the context of fuel/emissions savings.

4.2.5.2 Advanced highway construction practices

The following are the different advanced construction technologies that have the potential to reduce the overall CO_2 emissions from the construction stage.

1. **Slot dozing:** Slot dozing is a method of moving large quantities of material with a bulldozer using the same path for each trip so that the spillage from the sides of the blade builds up along each side; afterwards all the material pushed into the slot is retained in front of the blade. 'This method is particularly useful at sites where material is prone to spill from the sides of the blade due to large loads of relatively soft earth or movement downhill, and at sites where the load must be carried a long way' (Komatsu magzines).

Reduction in CO_2 emissions	Slot dozing can improve machine productivity by as much as 20% over conventional methods (ICF International, 2010), hence resulting in CO_2 emissions reduction.
Status of use	Slot dozing is being practiced in countries such as USA.[44] After talking to various stakeholders/ contractors, it was found that use of slot dozing technique in not popular in India.
Recommendation	Further research should be done on the benefits of using slot dozing techniques in Indian conditions.

2. Production of bituminous and concrete mix for the construction of roads emits large amount of GHG emissions. If the production of these mixes is optimized, significant CO_2 reduction from highway construction can be achieved.

Reduction in CO_2 emissions

Table 29: Measures for optimizing the production of bituminous mixes for road construction along with their CO_2 reduction potential

Carbon reduction measures	CO_2 savings in a plant (Tonnes/Year)
Stockpiling fine aggregates under roof on sloped concrete	290
Frequent replacement of worn flights in drier	40
Insulation of all vessels and pipelines containing heated materials	140
Asphalt product storage in closed silos	30
Burner fuel switch from HFO to natural gas	820

Source: (Oliver Stotko, 2011)

Status of use	At present, the above-mentioned interventions are not used in India. (This has been enquired from various highway professionals and contractors.)
Recommendation	The above-mentioned interventions show a lot of potential to save CO_2 emissions. Use of these measures to optimize the production of bituminous mixes for road construction should be encouraged through policies/guidelines. Also, awareness regarding the benefits of these measures should be created among various stakeholders/contractors.

4.2.5.3 Efficient transportation of construction material

As per the study, 'Greenhouse Gas Emissions Mitigation in Road Construction and Rehabilitation' carried out by East Asia and Pacific Region (EASTE), World Bank in 2011, about 30% of the GHG emissions from road constructions come from the transportation of materials. Thus, significant attention should be given to optimize the method of transportation of materials to the site of construction.

Reduction in CO_2 emissions	Modal shift to more efficient means of transport, namely, rail or water, results in 17 times (World Bank, 2011) lower emissions for long distances.
Status of use	At present, in India most of the construction materials are being transported through roads.

Indian examples

Table 30: Road stretches/projects known to have used railways for the transportation of coarse aggregate

Name of the road	State	Type	Length (km)
Four-laning of the Patna–Bakhtiyarpur section of NH-30 (green field project)	Bihar	National Highway	50.65
Six-laning of the Etawah–Chakeri (Kanpur) section of NH-2	Uttar Pradesh	National Highway	160.21

Source: Data collected by TERI

Recommendation	Rail and water transport for the construction materials results in the reduction of CO_2 emissions; it should be promoted through policy interventions like incentives for transporting material by energy efficient mode/s.

[44] https://www.epa.gov/sites/production/files/2015-09/documents/cleaner-diesels-low-cost-ways-to-reduce-emissions-from-construction-equipment.pdf

Potential of reducing CO_2 emissions on account of shifting aggregate transport from road to rail is discussed with the help of a project example in Uttar Pradesh.

BOX 6: EMISSIONS AND COST COMPARISONS FOR AGGREGATE TRANSPORTATION BY ROAD VS RAIL: ETAWAH–CHAKERI ROAD PROJECT IN UTTAR PRADESH

The six-laning of the Etawah–Chakeri section of NH-2 in the state of Uttar Pradesh was taken up under Phase V of the NHDP on a design, build, finance, operation, and transfer (toll) basis. The 160.212 km stretch starts from km 323.475 and ends at km 483.687. The project has been developed by the Etawah–Chakeri (Kanpur) Highway Private Limited, a special-purpose vehicle of Oriental Structural Engineers Limited. The construction work on the composite (some portion is bitumen and some is concrete) stretch started in March 2013 and was completed in April 2016.

The project required huge volume of coarse aggregate, to the tune of 453,316 tonnes, which was sourced from locations, such as Kabrai, Bhilua, and Gohad. To move coarse aggregate from the Kabrai mining site, the contractor used railways as the preferred mode of transport instead of road transport. The contractor has shared data only for the aggregate moved in a month by rail, which was about 60,000 metric tonnes (MT) from Kabrai. This has been used to do the emission and cost analysis for road vs rail movement of aggregate (as discussed below). The distance between the project site and the other two mining sites were much less as compared to Kabrai and rail connectivity was a challenge; therefore, road transport was used to move aggregate from Bhilua and Gohad mining sites. Figure 21 provides the route for rail and road, and the distances as given by the contractor of this projec.

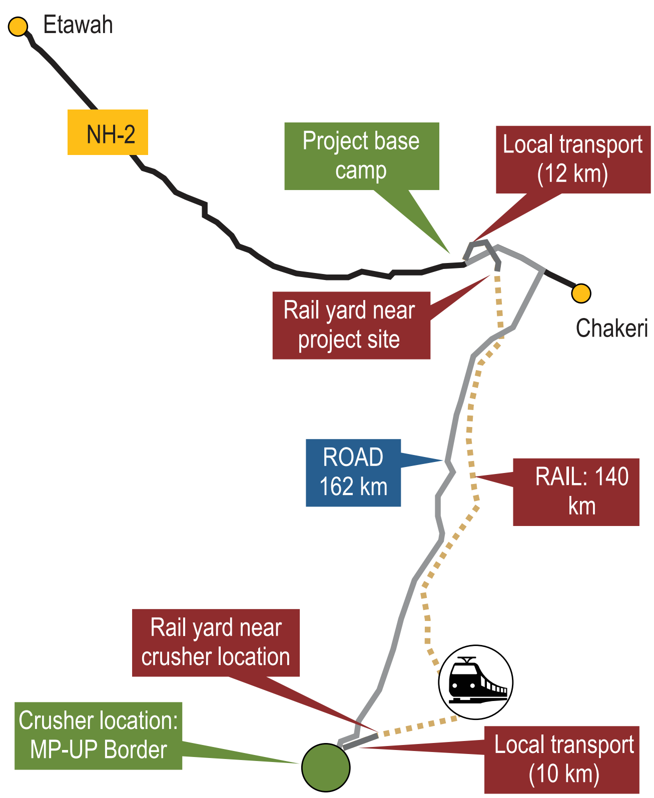


Figure 21: Transportation of aggregate from crusher location to project base camp: Road vs Rail

Rail Route: The rail route, as shown in Figure 1, starts from the crusher location (Prakash Bhamori in Madhya Pradesh) to Kabrai rail yard (10 km), where the material is transported by trucks/tippers (first mile). From Kabrai rail yard, the coarse aggregate is moved by rakes with a capacity of 4,012 tonnes to Bhimsen rail yard (near the project location). Thereon, the material is transported by trucks/tippers to the camp site (last mile).

Road Route: The road route covers a total distance of 145 km and the material is transported using trucks (average fuel efficiency of 3 km per litre) with an average loading of 33 tonnes. The number of trips made by trucks is estimated at 4,000 (from the stone crusher location to the camp site and back).

The data shared by the contractor of the Etawah–Chakeri project has been used to calculate the emissions and costs involved in the movement of coarse aggregate from the crusher location to the project location. A comparison between the road and rail modes for transporting aggregates, both in terms of CO_2 emissions and cost, is given below.

A. Emissions comparison: Road vs Rail

Figure 21 depicts the difference in CO_2 emissions involved while moving coarse aggregate using rail (also involving road transport for the first- and last-mile movement) vs entirely by road. As can be seen in Figure 22, moving coarse aggregate by rail results in CO_2 emissions of 158 tonnes, of which 100 tonnes is on account of rail operations and 58 tonnes on account of first- and last-mile movement by road. On the other hand, moving coarse aggregate from the crusher location to the project site entirely by road would have resulted in CO_2 emissions of 523 tonnes.

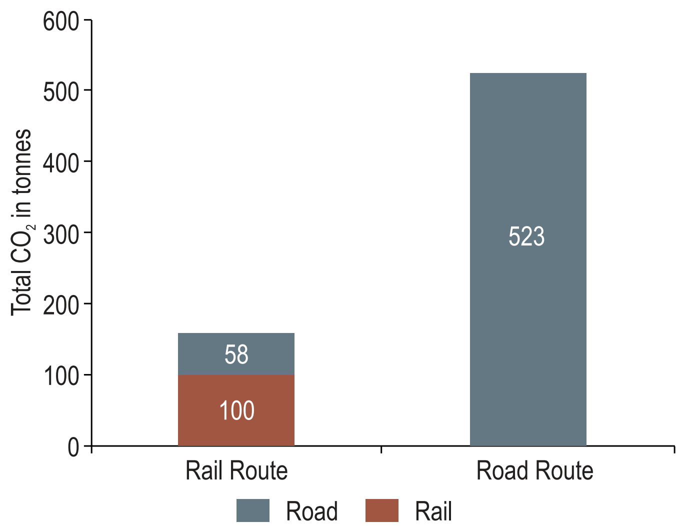


Figure 22: Comparison of CO2 emissions per month for the movement of coarse aggregate by road and rail

Source: TERI Analysis

B. Cost comparison: Road vs Rail

Moving coarse aggregate by rail involves a number of activities. These include loading of material on to tippers at the crusher location, unloading at the rail yard, loading to rail wagons, unloading at the rail yard close to project site, and loading on to tippers to be finally unloaded at the project camp site. This requires deployment of equipment and hiring manpower for supervision, handling of material, and security. It also involves wastage of material during loading and loading stages. Taking into consideration the costs of all these factors, the cost of moving aggregate by rail stands at about Rs 529 per MT, which is slightly lower than road transport at about Rs 560 per MT. Table 29 provides the cost differential of moving aggregate by road as compared to rail.

Table 31: Costing involved in the transportation of aggregate by road and rail modes in the Etawah–Chakeri six-laning project

Railway Handling: Components	**Amount/number**
Local transportation from crusher location to nearest rail head (Kabrai)	
Lead (km)	10.00
Rate (Rs/km/MT)	5.00
Transportation cost (Rs/MT)	50.00
Loading onto tipper trucks	-
Unloading at Kabrai Rail Loading Yard	
Rake loading cost (Rs/MT)	20.00
Additional loading overhead cost (idling of machinery) (Rs/MT)	23.33
Manpower supervision cost (Loading area) (Rs/MT)	2.00
Material wastage during re-handling	2%
Cost towards material wastage (Rs/MT)	-
Rail transit cost from Kabrai to Bhimsen (Rs/MT)	299.10
Unloading at Bhimsen Rail Yard (Rs/MT)	20.00
Loading cost onto tippers (Rs/MT)	14.00
Additional unloading overhead cost (idling of machinery) (Rs/MT)	14.00
Material wastage during re-handling	2%
Cost towards material wastage (Rs/MT)	-
Transportation from Railway station to project camp (km)	12.00
Rate (Rs/km/MT)	5.00
Transportation cost (Rs/MT)	60.00
Manpower supervision cost(Unloading area) (Rs/MT)	2.00
Additional miscellaneous overheads (Rs/MT)	25.00
Total cost by Rail (Rs/MT)	529.44
Road Handling: Components*	**Amount/number**
Lead from crusher location to Camp 1 (km)	162.00
Transit wastage	-
Transportation rate (Rs/km/MT)	3.45
Total cost by Road (Rs/MT)	558.90

*Note: Material is loaded onto truck at crusher location and unloaded at project location

Source: Oriental Structural Engineers Limited

4.2.6 Interventions during maintenance stage

4.2.6.1 Routine/Periodic Maintenance	
Effective preventive maintenance techniques/road surface treatments can be used to increase the life and quality of pavements so that less construction materials are required for the maintenance and roughness of road can be maintained so that there is less emission from vehicles plying on the roads. Road surface treatments are methods or materials for extending the lifetime of road pavements, delaying the need for major maintenance, or rehabilitation. There are various surface treatments that are practiced in India and around the world that include surface dressing, slurry seal, fog seal, microsurfacing, and chip seal.	
Key advantages	Advantages/importance of highway maintenance are as follows (Parkman, et. al., 2012): » Maintenance of roads improves safety as the possibility of accidents increase due asset deterioration. » It reduces environmental degradation as a well-maintained road results in better riding quality and lower emissions. » Well-maintained roads reduce the vehicle operation cost. » Well-maintained roads improve the overall accessibility to the area.
Savings in CO_2 emission	'A rough road slows down traffic and reduces efficiency, increasing fuel use and CO_2 emissions by 5–10 percent or more' (ADB, 2010). According to (ADB, 2010a), emissions (CO_2 tonnes/km/year) increased by 1.6% when the road roughness increased from 2 m/km to 4 m/km; by 3.3% when it increased to 6 m/km; and by 5.8% when it increased to 9 m/km.
Status of use	Maintenance techniques, such as surface dressing, slurry seal, and infrared patching method have been extensively used in Gujarat, Maharashtra, and Delhi.[45] Velocity patching method in India has not been encountered so far. This method is practiced in UK.
Recommendation in Indian guidelines	IRC: 82-1982 gives a detailed outline of the guidelines regarding the maintenance of bituminous surface of highways. It details the different type of pavement failures and the different types of maintenance techniques. The infrared patching method is in the list of new materials/techniques/equipment accredited by IRC as 'Nu-PhaltInfra Red Pothole Recycling Repairing System'.
Recommendation	Periodic maintenance is very crucial as it has a bearing on the fuel consumption on account of rolling resistance/slow speed. The effects of maintenance of the roads have been discussed in detail in the next chapter 'Good-quality vs Bad-quality National Highways: Life Cycle Emission Analysis'. Proper periodic maintenance of the roads is, therefore, recommended. It is also recommended that adequate fund is allocated towards the maintenance of NHs.
4.2.6.2 Microsurfacing	
Microsurfacing is a preventive maintenance technique. In this technology, 3–6 mm sized bitumen aggregates are treated with a special emulsion. A mixture of polymerized bitumen emulsion, specially graded fine aggregates along with cement, water, and the necessary additives is prepared. All the materials are mixed homogeneously on-site in a special microsurfacing machine. The mixture prepared is uniformly spread all over the surface with the spreader box attached behind the machine (Rajesh S. Gujar *et al*., 2013). The method can be used for preventive and periodic renewal treatment for roads.	
Key advantages	The key advantages of microsurfacing are:[46] » With microsurfacing, life of the highway can be extended by at least seven years. » It is quick in application (one km in 35 minutes), because of which quick opening of traffic and hold up of traffic is comparatively less as compared to other technologies. » It is environment friendly as no heating is required. » It improves the skid resistance of the surface by making it waterproof and provides surface stability.

[45] Sources : (IRC-110-2005), http://siteresources.worldbank.org/INTSARREGTOPTRANSPORT/3221770-1165232837016/21149972/12-Final-SurfaceDressing-Rawal-Gujarat.pdf and IRC-82-1982

[46] (IRC: SP-100, 2014)

Savings in cost	40% reduction in cost per km is seen in microsurfacing as compared to HMA (IRC: SP-100, 2014). '*The cost of road asphalting reduces by 50% in the technology. Hot mix tar costs Rs 400 per sq m while micro surfacing costs only Rs 200 per sq m. Layer of 40–50mm is laid in hot mix while only 4-6mm is laid in micro surfacing.*'[47]
Savings in CO_2 emission	If we compare a 7-year life for the microsurfacing treatment having a thickness of 9.525 mm with a 10-year life of a hot mix overlay with a 38.1 mm thickness, it was seen that the CO_2 emissions were found to be 13.40 kg/lane km; and, in the case of hot mix overlay, the CO_2 emissions were 1,078 kg/lane km, thereby leading to 99% reduction in CO_2 emissions as compared to HMA (Rajesh S. Gujar *et al*., 2013).
Status of use	'*Microsurfacing is now used throughout Europe, the US, and Australia*' (Ben Broughton *et al*, 2012). Microsurfacing is being used worldwide since the 1970s. In India, it is in use since 2000, however, in limited road stretches by Delhi PWD, New Delhi Municipal Corporation (NDMC), Uttarakhand PWD, Madhya Pradesh PWD, and Gujarat. It was suggested by the MoRTH that '*The implementing agencies may ensure that at least 25-30% of total eligible length for Periodical Renewal, preferably in a continuous stretch, is covered by microsurfacing or other similar type of treatment in future.*'[48]
Recommendation in Indian guidelines	IRC has published code IRC: SP 81-2008 which details with the specifications of design and methodology of microsurfacing technology including different types of microsurfacing and its constituent materials. The use of microsurfacing is also recommended in the Specifications of Roads and Bridge Works' (2013).
Indian examples	(see Table 32 below)
Recommendation	Given the advantages offered by microsurfacing, it is recommended to promote microsurfacing for the maintenance of highways, especially for highways recording heavy traffic. It is also recommended to create awareness among various concerned stakeholders about the benefits of this technology. In addition, adequate capabilities in using microsurfacing technology need to be created amongst the stakeholders.

Table 32: Key NH projects known to have used microsurfacing

Name of the road	State	Type	Length (km)
Ahmedabad–Mehasana Road Project	Gujarat	NH	52.6
Vadodara–Halol Road Project	Gujarat	NH	42.0
Ahmedabad–Vadodara Expressway	Gujarat	Expressway	93.1
Rajkot–Gondal–Jetpur NH - 27	Gujarat	NH	68.6

Source: IL&FS Transportation Networks Limited and L&T IDPL

4.3 Status of engineering interventions

The MoRTH, NHAI as well as IRC have been continuously trying to promote the use of green/alternative materials and technologies for constructing and maintaining NHs. Despite these efforts, these materials/technologies have been receiving lukewarm response from the project engineers, designers and consultants.[49] Table 33 lists out the measures taken by the authorities and IRC to encourage the adoption of green/alternate technologies.

[47] http://timesofindia.indiatimes.com/city/nagpur/NMC-mulls-micro-surfacing-to-asphalt-roads-even-during-rains/articleshow/53051947.cms; last accessed on September 1, 2017

[48] http://morth.nic.in/showfile.asp?lid=2415

[49] http://morth.nic.in/showfile.asp?lid=2631

Table 33: Measures taken by the MoRTH and IRC to promote the use of alternate materials/ technologies

S. No	Year	Measures taken
Committees/accreditation		
1	October 15, 2009	The 'Committee for Accreditation of New Materials and Techniques', comprising 25-members, was formed to evaluate the use of new materials/technologies (IRC, 2016).
2	June, 21 2010	The NHAI lays down the procedure for the adoption of different materials/techniques that are accredited by IRC in national highway projects.[50]
3	June 7, 2013	The MoRTH decided that the new/alternative materials/technologies, proven in India or abroad should be considered for accreditation and subsequently for adoption in the highways sector. It also suggested that new materials/technologies should be given priority in field trials and the performance of these technologies should be evaluated over a period of time to enable the formulation of guidelines and codes of practice for their future usage on the NHs.[51]
4	November 20, 2013	Life cycle cost analysis should be done as a part of feasibility studies/detailed project report.
5	February 11, 2015	In order to encourage the use of environmentally-friendly alternatives materials/green technologies in highway construction, the MoRTH constituted an expert committee to recommend best practices in respect of material and machinery for economical, speedy and durable construction of highways. (IRC, 2016)
6	2015	The Indian Roads Congress formed a 'Committee on Reduction of Carbon Footprint in Road Construction and Environment (G3)'. The main aim of this committee is to appropriate carbon calculators and processes for getting carbon credits in the life cycle analysis for road/ transportation projects under the Environmental Management Plan. (IRC, 2016)
Material-specific interventions		
7	September 26, 2002	Use of polymer/rubber modified bitumen during the periodic renewal of highways.[52]
8	January 4, 2010	The NHAI recommended the use of slurry seal and microsurfacing as the maintenance treatment for preventive maintenance and rectification of surface defects.[53]
9	January 8, 2010	The NHAI decided that steel furnace/blast furnace/copper slag aggregates should be used in granular sub-base provided it satisfies the physical requirements/grading as stipulated in the specifications.[54]
10	January 12, 2010	The NHAI encouraged the use of stone matrix asphalt as a wearing course in its projects depending upon the site requirements and life cycle costing.[55]
11	February 24, 2010	The NHAI encouraged the PIU's to use of reclaimed asphalt pavement in WMM/GSB according to the Clause 517 of the 'Specifications for Road and Bridge Works'.[56]
12	August 6, 2014	The Ministry selected 18 different materials/technologies to evaluate their suitability in different states on a trial basis.[57]

[50] http://www.mangalgiri.in/tech/t-62.10.pdf
[51] MoRTH circular No:- RW/NH- 35075/1/2010-S&R(R)
[52] MoRTH circular No:- RW/NH-33044/10/2000-S&R
[53] http://www.nhai.org/circular/circulars/tech/t-40.10.pdf; last accessed onJune 22, 2017
[54] http://www.mangalgiri.in/tech/t-41.10.pdf; last accessed on June 22, 2017
[55] http://www.mangalgiri.in/tech/t-42.10.pdf; last accessed on June 22, 2017
[56] http://www.mangalgiri.in/tech/t-48.10.pdf; last accessed on June 22, 2017
[57] MoRTH circular No:- RW/NH- 33075/1/2010-S&R(R)

13	2015	Recommended practice for the recycling of bituminous pavements: '*Statutory requirement for road projects beyond a size of 100 km based on the principles like less energy intensive technology by reclaiming the damaged or unserviceable pavement materials by milling, mixing fresh materials with reclaimed materials, and producing mixes.*'
14	November 19, 2015	Use of plastic waste in hot mix wearing coat for the periodic renewals in roads within a 50 km periphery of urban areas with a population more than 5 lakh[58]. Guidelines for the use of plastic waste was issued by the IRC in 2013 (IRC:SP-98-2013)
15	September 28, 2016	Use of microsurfacing for the renewal course, maintenance, and repair on NHs.[59]
16	2017	149 new materials/techniques accredited by the IRC.[60]
17	Multiple years	Standards for the use of cold mix technology (IRC:SP:100-2014), fly ash in construction (IRC:SP:58-2001), warm mix asphalt technology (IRC:SP-101-2014), and gap-graded bituminous mixes using crumb rubber (IRC:SP:107-2015)
Source: Compiled by TERI from circulars and annual reports of the MoRTH, NHAI, and IRC		

As mentioned earlier, despite all the efforts mentioned in Table 33, the response towards the use of green/alternate materials and technologies has been subdued. TERI held several rounds of discussions with the stakeholders involved in the road construction sector to understand the issues pertaining to the slow implementation/ adoption of green or alternative materials. Some of the major hurdles highlighted by the stakeholders include requirement of specialized machinery and skill, higher initial cost, non-availability of materials in large volume, etc. Table 34 gives a snapshot of the engineering interventions discussed in section 4.2, and highlights the issues faced in using these green/alternate materials.

Table 34: Status of implementation, issues faced while using green/alternative materials

S. No	Intervention	Recommended in	Status of implementation	Remarks
Green Construction Technologies				
1	Warm-mix asphalt	IRC-SP:101-2014	Pilot/low penetration	It requires specialized construction machinery and testing labs The construction workers are not trained/ unskilled; as a result, the performance of the road might suffer The technicians/workers find it difficult to maintain the temperature of the bitumen between 110 °C–130 °C The initial cost is high; as a result, the use of warm-mix technology is economically viable only for large-scale projects
2	Cold-mix asphalt	IRC-SP-100-2014 (Only rural roads)	Widely used for maintenance purposes	It is mainly used for maintenance purposes

[58] MoRTH circular No:- RW/NH- 33044/24/2015-S&R(R)
[59] MoRTH circular No:- RW/NH- 33044/68/2016/S&R (R)
[60] http://www.irc.nic.in/WriteReadData/LINKS/List%20of%20Accrediated%20149%20New%20Materialsfe9c9416-3f77-40a6-af34-3e6b1a843064.pdf; last accessed on June 22, 2017

3	Micro surfacing	IRC: SP 81-2008 and NHAI circulars	Commercially used	It requires specialized construction machinery It is mainly used by BOT operators Since it is a monopolistic item, many contractors prefer not to use it
4	Soil stabilization	IRC: 028, IRC: SP 89-2010 and IRC:SP-19-2010	Pilot/low penetration (Project specific)	It needs specialized machinery to carry out construction work The use of soil stabilization is project specific
Alternate Materials/technologies				
5	Reclaimed asphalt pavement	IRC: 120-2015	Pilot/low penetration	It requires specialized machinery It is mainly used for periodic maintenance works Since most of the NH network is under construction or is newly constructed, its popularity is expected to grow as more roads come under the periodic maintenance phase
6	Geo synthetics	IRC 113-2013	Commercially used	Geo-synthetics are generally used where CBR value is low It is generally used for soil stabilization and erosion control on the embankment of the roads Initial cost is high
7	Plastic waste	IRC: SP 98-2013 and NHAI circulars	Pilot/low penetration	Intensive segregation of waste is required For remote sites, far from urban areas, the transportation cost for plastic waste is high
8	Rubber waste	IRC: SP 53-2010 and IS 15462: 2004	Commercially used	Sufficient performance report for the use of crumb rubber bitumen is not available Use of crumb rubber bitumen is not advised in extreme temperature as it leads to various pavement failures
9	Fly ash	IRC: SP-58 2001	Commercially used	The CBR value of fly ash is very low The transportation cost is high for the project sites that are far from power plants
10	Concrete recycled aggregate/ construction and demolition (C&D) waste	CPCB guidelines- 'Guidelines on Environmental Management Of C & D Wastes'	Pilot/low penetration	The relevant code is under process and is expected to be finalized soon Mainly used in urban areas as the transportation cost to any other remote location would be high
11	Ground granulated blast furnace slag	NHAI Circular	Pilot/low penetration	Availability of ground-granulated blast furnace slag is very low Most likely to gain popularity in the coming years
12	Copper slag	NHAI Circular	Pilot/low penetration	Availability of copper slag is very low Most likely to gain popularity in the coming years
13	Foundry sand	NIL	Pilot/low penetration	More research/pilot projects required to be carried out to examine the potential of its use in NHs

14	Marble dust	NHAI Circular	Not used	The use of marble dust is more cost effective in building construction as compared to road construction
15	Marginal Aggregates	IRC SP: 72 and IRC: SP 20-2002 (Mainly used for rural roads)	Pilot/low penetration	Use of marginal aggregates is not advised in NHs as the desired strength is not achieved It can be used in footpaths and shoulders
16	Vetiver grass	NIL	Commercially used	Vetiver grass is being used in Uttarakhand and in the North-Eastern states Should be used extensively in other coastal and hilly regions
17	LiDAR	Made mandatory for new projects	Commercially used	-
18	Mechanical retexturing	NIL	Pilot/low penetration	This technology is mainly used for maintenance It requires specialized machinery
19	Surface dressing	IRC-110-2005	Commercially used	It is very popular and is used for the maintenance of roads
20	Slurry seal	IRC-82-1982	Pilot/low penetration	This technology is used to fill cracks in roads This technology is mainly used in urban roads
21	Infrared patching method	NHAI Circular	Not used	This technology requires specialized machinery
22	Velocity patching method	NIL	Not used	This technology requires specialized machinery
Note: Based on discussions with various stakeholders, including officials from the MoRTH, NHAI, IRC, etc.				

4.4 Mainstreaming strategies for developing low-carbon National Highways

It has been extensively discussed that NHs contribute a significant share in the total road transport-related carbon emissions. The different potential interventions that can help reduce the CF during the construction, operations, and maintenance phases of NHs have been discussed in sections 4.1 and 4.2. It is important for the implementing agencies (MoRTH/NHAI/PWD) to take steps right from the planning and design stages to the operations stage with a focus on reducing carbon emissions during the entire life cycle of NHs. There is a need to mainstream the previously discussed CO_2 emission reduction strategies into the policy framework.

BOX 7: INTERNATIONAL BEST PRACTICES FOR LOW-CARBON HIGHWAYS

Internationally, several measures have been undertaken to reduce the CO_2 emissions during construction, maintenance, and operation phases. Majority of the measures pertain to emission reduction during the operations phase, which is also commensurate with its share in total emissions. For example, Australia has a policy that extends fuel tax credits to vehicle owners who comply with the maintenance schedule endorsed by the transport department. The UK Department for Transport has initiated a Safe and Fuel Efficient Driving programme for heavy- and light-goods drivers to reduce operation-related CO_2 emissions. For the construction and maintenance phase, emission reduction, restrictions on the use of virgin materials, and push towards the use of recycled and durable/ sustainable materials have been adopted as part of policy measures by countries, such as Sweden, Denmark, and Australia. *Annexure 8* provides details about international best practices adopted to reduce CO_2 emissions on account of highway construction, maintenance, and operations.

Mainstreaming carbon emission reduction strategies for the NH sector will entail varied measures, including institutional, fiscal, and regulatory measures. These have been discussed in Table 35.

Table 35: Mainstreaming of low-carbon emission strategies for NHs in India	
Topics	**Recommendations, Responsibilities, and Implementation Timeline**
Construction and maintenance phases	
CO_2 emissions accounting and consideration of low-carbon interventions to be made mandatory at the DPR stage	***Recommendation:*** The excel-based NH model/tool developed by TERI or other similar tools could be used to estimate CO_2 emissions during the construction and maintenance phases. This will facilitate undertaking optimization exercise with regard to lead, material/fuel/technology and efficiency and will eventually help in figuring out alternative plans/green materials/green processes, thereby resulting in lower CO_2 emissions during the construction and maintenance phases. **It is recommended that an emissions-accounting exercise should be undertaken by DPR consultants while undertaking project-feasibility studies; the potential low-carbon/green interventions should be clearly identified in the DPR along with the possible reductions in CO_2 emissions on account of these interventions.** The potential low-carbon/green interventions that can be adopted at the project stage are summarized in Appendix 10 and can be used as a checklist by the MoRTH/a competent agency for evaluating the DPRs for their consideration of low-carbon interventions. Every new project should evaluate these low-carbon materials and technologies for their application in the project and provide a clear recommendation on which all materials /technologies/practices are incorporated/proposed to be used in the project. A competent agency/authority of the owners should check and approve this analysis in the DPR. Inclusion of low-carbon interventions in DPRs will help establish the appropriate (green) materials and technologies which can further be used to invite the bids accordingly (with adequate provision of low-carbon materials and technologies in the bid document). **The DPR consultants will need to be trained/made aware of the requirement of considering low-carbon interventions in the DPR and estimating the carbon emissions of the project, which in turn implies the need for planning and executing appropriate training programmes.** ***Agency responsible (to take it forward):*** MoRTH ***Expected timeline (required for implementation^):*** Medium term
Institutionalize a Carbon Rating System for National Highways	***Recommendation:*** As stated above, emissions estimation during the construction and maintenance phases should be done at the DPR stage to calculate the life cycle of CO_2 emissions for all the NH stretches. While the initiative will help identify project specific low-carbon interventions, it will also help generate a robust database of CO_2 emissions from different stretches in different terrains/climate zones. **This database can help initiate a 'Carbon Rating System' which could help quantify the performance of the NH projects on a carbon footprint scale.** It can be a useful decision support/making tool. To encourage the estimation of carbon emissions at the DPR stage and the adoption of low-carbon interventions in project design, the MoRTH could then provide incentives, in terms of awards or monetary incentives, to recognize low-carbon initiatives/low-carbon NH projects through this carbon rating system. With regard to institutionalization, a pool of experts for evaluating carbon emissions estimated and low-carbon interventions adopted in DPRs could be housed in MoRTH under an appropriate department or the unit proposed in Component II of the study (section 6.2, Component II). An external agency could also be engaged to help these experts/units in facilitating the work related to the life cycle CF estimation of NH projects. ***Agency responsible:*** MoRTH ***Expected timeline:*** Medium term

Create database for estimating and monitoring CF of NHs	***Recommendation:*** Primary data from site engineers of various projects were collected to estimate CF of NHs. However, the entire process of collecting data was challenging. For a number of projects, complete data was not available for the estimation purpose. **It is, therefore, recommended that a template for data collection is made and reporting is made mandatory for the PIUs/contractors.** A database should be created and maintained at the central level to help estimate and monitor the emissions/changes in emissions. The questionnaire used to collect data under this study for the three phases of the NHs could be used for this purpose (refer to Annexure 3). The cell could be the nodal point for data collection and management. ***Agency responsible:*** MoRTH ***Expected timeline:*** Short term
Enforcing IRC guidelines and codes for construction materials and methods	***Recommendation:*** There are several materials/methods, such as warm/cold-mix asphalt, microsurfacing, geosynthetics, etc., discussed in section 4.2, which are covered under the IRC guidelines/rules, but are not widely deployed or used during the construction and maintenance of NHs due to various reasons, including lack of awareness on part of the contractors/developers (refer to section 4.3). **For these materials, more awareness or more demonstration projects need to be undertaken. It is suggested that, wherever possible, at least service roads as well as service areas along NHs be constructed using alternate materials/technologies.** It is recommended that the relevant codes and guidelines be updated by the IRC and its provisions be made mandatory by the MoRTH (refer to section 4.2 for specific recommendations for different materials/technologies). Also, recommendations made by the expert committee on the Best Practices in Road Construction, which was chaired by Mr S R Tambe, should be referred to (MoRTH, May 2016). Some of the key recommendations of the committee are as follows: » *Contractors should be given freedom to design the projects within the limits set in the concession agreements and standard specifications. A panel of experts should be constituted at the national level to expedite approvals to the proposals for using innovative technologies/ materials.* » *The current approach—the least cost method (L1)—of selecting contractors should be changed to a quality- and cost-based selection method.* » *Distinction between bona fide and mala fide should be clearly made to prevent officials from being wrongfully penalized for their decisions. It recommended that the existing vigilance procedures should be amended to ensure that bona fide interests of projects are protected. Further, performance assessment of officials implementing the projects should be carried out.* » *Drafting of IRC codes should be assigned to experienced consultants on a payment basis as is practised in other countries. Further, the funding to the IRC should be increased.* » *Approval of environmental clearances should be expedited and a well-defined policy for cutting of trees, etc. should be evolved.* ***Agencies responsible:*** IRC, MoRTH, NHAI, and state PWDs ***Expected timeline:*** Medium term

<table>
<tr>
<td>Examine and appropriately include new construction materials and methods under IRC Guidelines/ Codes</td>
<td>
Recommendation: There are materials, such as marginal aggregates, copper slag, ground granulated blast furnace slag, foundry sand, and marble dust, which are used/practised in foreign countries but are not covered under any IRC guidelines/codes for NHs (refer to section 4.3). Adding these materials in the IRC guidelines will give the contractors an option to procure locally available materials and reduce the lead for procuring conventional materials from far-off places.
In addition, construction methods/techniques such as slot dozing need to be adopted by the contractors which would require a push from the developers or implementing authorities, such as the MoRTH and NHAI. It is recommended that incentives should be provided to push the use of such green technologies/materials/equipment/ processes.
It is recommended that research and development and pilot projects are undertaken for including new materials/technologies in IRC guidelines/codes.
Agencies responsible: Indian Roads Congress, MoRTH, Research institutes such as the CRRI
Expected timeline: Long term
</td>
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<tr>
<td>Revise Detailed Project Report (DPR) document</td>
<td>
Based on stakeholder consultations regarding the use of green/alternate materials and adoption of other low-carbon practices, it has been suggested that changes in the DPR document are necessary. TERI reviewed documents related to DPR, including 'Guidelines for Procurement, Preparation, Review and Approval of DPR' (MoRTH, 2016b). The following are some of the suggestions that should be included in the DPR document to fast track the adoption of green/alternate materials during the construction and maintenance of NHs.
» As stated earlier, carbon accounting of construction/maintenance activities should be made mandatory at the DPR preparation stage. DPR document should be revised for same.
» The evaluation of bids is done on the basis of technical and financial proposals. In order to promote the use of green/alternate materials, compulsory evaluation of these materials and technologies, those that have been already recommended in the IRC guidelines, should be undertaken as part of the technical proposal. A checklist of green/alternate materials and technologies has already been included in the report. Qualitative evaluation of these materials should be done as part of the inception report and quantitative analysis should be done as part of the feasibility report.
» It should be noted that in order to encourage the use of green/alternate materials in NHs, life cycle analysis should be made mandatory for every project and it should be in line with the General Financial Rule 2017 (Clause 136) (Department of expenditure, 2017). In addition, the total life cycle cost and emissions of the project should be compared under the following two scenarios:
» Scenario 1 (S1): When conventional materials technologies are used
» Scenario 2 (S2): When green/alternate materials are used
Tentative format for the two scenarios
<table>
<tr><th rowspan="2">Project Details (length, lanes, type, etc.)</th><th colspan="2">Conventional material/ technology (S1)</th><th colspan="2">Alternate material/ technology (S2)</th><th colspan="2">Percentage variation</th></tr>
<tr><th>Cost per km (Rs)</th><th>CO_2 emissions per km (tonnes)</th><th>Cost per km (Rs)</th><th>CO_2 emissions per km (tonnes)</th><th>Cost per km (Rs)</th><th>CO_2 emissions per km (tonnes)</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
Since the use of these green/alternate technologies are project specific, including a comparative analysis, the projects would help stakeholders to understand the potential of the use of these green/alternate materials in different conditions.
Agencies responsible: MoRTH, NHAI
Expected timeline: Medium/long term
</td>
</tr>
</table>

Constitution of R&D innovation support fund	**R&D innovation support fund should be constituted to encourage/promote the use of green materials/technologies**. Under this, some part of the incremental cost on account of using alternate/green materials can be borne by the implementing authority. ***Agency responsible:*** MoRTH ***Expected timeline:*** Short/Medium term
Operations phase	
Expedite implementation of fuel efficiency norms for cars and HDVs	***Recommendation:*** The GoI has notified fuel efficiency standards for passenger cars (BEE, 2014) (BEE, 2015) and HDVs[61]. As stated in section 3.2, HDVs account for the highest share in carbon emissions implementation of fuel efficiency standards will go a long way towards reduction in emissions during operations phase. **The implementation of these fuel efficiency norms should be expedited so that the effect of fuel efficient cars and HDVs with regard to lower-carbon emissions could be realized**. ***Expected timeline:*** Short term
Improve the inspection and maintenance (I&M) system for on-road vehicles	***Recommendation:*** Poorly maintained vehicles are a major source of emissions from the transport sector. The practice of scheduled maintenance of commercial vehicles is almost missing or, at best, taken up in the unorganized sector (ex-OEMs). **It is recommended that a robust inspection and maintenance system for on-roads vehicles is implemented to check emissions on account of non-maintenance of vehicles.** Key recommendations in this direction are as follows:[62] » The vehicles which do not have on-board display (OBD) units installed should be tested at the existing PUC facilities. » There is a need to improve the capacity of existing PUC centres over time to become a part of an enhanced overall I&M system. » OBD systems should be made mandatory for all vehicles by 2020. » Introduction of more accredited inspection centres, like in Nasik, can serve the purpose of testing the vehicles for road worthiness. » Integration of vehicle insurance and vehicle inspection. » Mandatory for all vehicles to carry a visible I&M sticker at all times. » Conducting annual testing of vehicles across India rather than quarterly or biannual PUC check. ***Agency responsible:*** MoRTH ***Expected timeline:*** Short to medium term
Notify a policy for scrapping of old vehicles	***Recommendation:*** Old/inefficient vehicles are also big source of carbon emissions, which should be phased out in a planned manner. In May 2016, the MoRTH came out with a concept note on Voluntary Vehicle Fleet Modernization Programme to encourage vehicle owners to replace their old ones with the new ones. **It is recommended that the programme should be implemented as early as possible and the replacement/scrapping of old vehicles be made mandatory instead of voluntary.** ***Agencies responsible:*** MoRTH and DHI ***Expected timeline:*** Short term

[26] https://beeindia.gov.in/sites/default/files/HDV%20Gazette%20Notification.pdf

[62] http://shaktifoundation.in/wp-content/uploads/2014/02/Position-Paper-Improving-inspection-and-maintenance-system-for-in-use-vehicles-in-India.pdf; last accessed on August 10, 2017

Promote better maintenance practices for NHs and increased funding towards the same	***Recommendation:*** Better maintained roads—lower rolling resistance (roughness index) and lesser potholes—is one of the measures to attain lower CO_2 emissions during the operations phase. **It is, therefore, recommended that adequate allocation is made towards highway maintenance so that there is no delay in maintenance on account of fund constraint**. There is a need to undertake proactive maintenance work as compared to the current practice of ad-hoc provision for the maintenance of NHs. This is important, especially for projects developed on the basis of engineering, procurement, and construction, as NHs developed on the PPP basis have in-built maintenance clause within the contract. Maintenance-related recommendations have been listed in the 'Report of the Working Group on Central Roads Sector' for the Twelfth Five Year Plan,[63] which should be revisited by the authorities. Some of the key suggestions include: » Develop sound 'Maintenance Strategies' with planned interventions of maintenance inputs » Do away with the traditional system of funding maintenance and repair (M&R) activities under non-Plan and take up M&R under Annual Plans separately segregated from construction » Develop a system of maintaining and periodically updating the database on the inventory of roads, bridges, and other structures on NHs including their condition as decision support system for prioritizing development and maintenance works, namely, Pavement Management System and Bridge Management System » Encourage using equipment for quick repairs of potholes, slurry seal machines, combined bitumen sprayer and chip spreader, and cold/hot recycling plants to improve the maintenance culture » Reorganize the maintenance operations by replacing the road gang with mechanized mobile units to improve the productivity of the existing work force Some of the suggestions made under the Report of the Working Group on Central Roads Sector for the Twelfth Five Year Plan such as increasing the cess on fuel (from Rs 2 per litre to the current level of Rs 6 per litre[64]), and undertaking maintenance work through operate-maintenance-transfer basis have been carried out by the MoRTH. Other suggestions made in the report should also be considered for the maintenance of the NH network. Adequate allocation of fund towards maintenance activities, as prescribed under the Report of the Committee on Norms for Maintenance of Roads in India, is also required (MoRTH, 2001). Currently, only 40% of the total fund required for the maintenance of national highways is made available to the implementing authorities under the budget.[65] There is a need to revisit the norms/formulae for estimating the maintenance fund requirement based on traffic plying on NHs. The norms were formulated by the committee titled 'The Norms for Maintenance of Roads' were compiled in 2001. The report has suggested that '*basic norms should be reviewed again only at the beginning of each plan period or 5 years, whichever is later*'. ***Agencies responsible:*** MoRTH/State PWDs ***Expected timeline:*** Short to medium term

[63] http://planningcommission.nic.in/aboutus/committee/wrkgrp12/transport/report/wg_cen_roads.pdf; last accessed on June 9, 2017

[64] http://indiabudget.nic.in/budget2015-2016/ub2015-16/cen/dojstru1.pdf; last accessed on June 9, 2017

[65] http://pib.nic.in/newsite/PrintRelease.aspx?relid=73941; last accessed on June 9, 2017

Encouraging the shift to larger trucks	***Recommendation:*** As discussed in section 4.1, shifting to larger trucks offers significant potential in reducing energy consumption and CO_2 emissions levels by making their operations efficient. It is also recommended that for these larger trucks, the engine size of >9 litres is considered to keep an optimum engine-to-weight ratio. '*Engines between 3 and 7 litres make up almost 99% of the total sales market*' (Sharpe, 2015). The low engine-to-weight ratios in the Indian HDV segment leads to lower efficiency and, therefore, the speed of trucks. It is recommended that engine-based standards/categorization should be developed depending on the use/purpose of HDVs.[66] For instance, if an HDV is used for heavy haulage (>25 tonnes), then trucks with higher-engine capacity of >9 litres should be preferably used. **Adoption of advanced-truck technology should be incentivized by the government.** ***Agency responsible:*** MoRTH/Department of Heavy Industries (DHI) ***Expected timeline:*** Medium to long term
Move towards the adoption of electric vehicles	***Recommendation:*** As discussed in section 4.1, adoption of electric drivetrains for vehicles operating on highways should be considered as one of the emissions mitigation strategies for reducing the emissions footprints of highways. **Adequate infrastructure (charging stations) is, therefore, required on the NHs to boost the adoption/penetration of electric vehicles while simultaneously incentivizing the uptake of electric vehicles through demand incentives.** ***Agency responsible:*** Integrated approach involving relevant ministries and departments to be coordinated by NITI Aayog ***Expected timeline:*** Medium to long term
Move towards higher share of public transport	***Recommendation:*** Dedicated effort towards shifting passenger mobility from cars to buses could help mitigate emissions resulting on NHs in India. Efforts to increase the service quality, reliability, and safety of buses could potentially shift some of the existing passenger traffic from passenger cars to buses. ***Agencies responsible:*** MoRTH and State Road Transport Corporations/Undertakings ***Expected timeline:*** Medium to long term
Create carbon sinks through afforestation and reforestation	***Recommendation:*** In September 2015, the MoRTH came out with the Green Highway Policy-2015 (plantation, transplantation, beautification, and maintenance) to develop a green cover along NHs, which would also serve as a natural sink for air pollutants. Currently, the pace of plantation is slow as about only 1,500 km of NHs witnessed a plantation drive during 2016–17, as compared to the 8,200 km of NHs constructed during the same year. **It is recommended that the process of tree plantation be expanded to cover the entire NH length.** ***Agencies responsible:*** MoRTH (including NHAI, NHIDCL, and state PWDs) ***Expected timeline:*** Short term to medium term
Note: ^ Short term: <1 year; Medium term: 1–3 years; Long term: 3–5 years	

[66] http://www.theicct.org/sites/default/files/India%20HDV%20FE_webinar_11Aug2015_vfinal_for%20distribution.pdf

5 Good-quality vs Bad-quality national highways: Life Cycle Emission Analysis

5

Good-quality vs Bad-quality national highways: Life Cycle Emission Analysis

One of the major problems faced by the Indian transport industry is low average speed, which translates into low average distance travelled per day. It has been estimated that a typical truck in India clocks 250–400 km per day (60,000–10,000 km per year) against 700–800 km per day (400,000 km per year) in developed countries (TCI, 2009). There are several reasons contributing to the low average speed/ distance covered by Indian trucks, including delays at interstate check posts, congestion at toll plazas, and poor quality of road infrastructure.[1]

Improving the quality of pavement through timely maintenance (annual as well as periodic maintenance) is one of the key interventions which could lead to reduced congestion, improved vehicle-fuel efficiency, and lower carbon emissions. Also, as has emerged from the results discussed in Chapter 3, 'Estimation of carbon footprint: Results', the maximum contribution to the CO_2 emissions from NHs is on account of vehicular movement during the operations stage. It is, therefore, important that efforts are made to improve the fuel efficiency of vehicular movement on NHs; improving pavement/riding quality on highways is one of the interventions that can enable this.

This chapter discusses the estimated carbon-reduction potential of developing 'good-quality' highways by establishing a relationship between smoothness of pavements and fuel consumption using TERI's excel-based NH model. Also, international studies have been referred to understand the relationship between roughness index/smoothness of the pavement and fuel consumption.

[1] https://www.tcil.com/tcil/pdf/study-report/a-joint-study-report-by-tci&-iim-2009-10.pdf

5.1 Roughness of pavements

Roughness is one of the key indicators of the riding quality of any pavement, including vehicular speed and operating costs, comfort, etc. A scale, the International Roughness Index (IRI), was developed by the World Bank in the 1980s which is now adopted by several countries and is used to measure the quality/smoothness of pavements. Figure 23 indicates the range of IRI values for different types of pavements and the corresponding speeds.

In the late 1990s, around the same time when the GoI was initiating the ambitious National Highways Development Programme (NHDP), the Federal Highway Administration (FHWA) launched a plan to enhance the riding quality of roadways across the US. Under this, the FHWA planned to bring '93% of its road network under the "good" category with IRI value of less than 95 inches per mile and "acceptable" category with IRI value less than 170 inches per mile'.[2] This was targeted to be achieved within a period of 10 years from the date of announcement. It was also one of the first such projects, which took the roughness index as the key performance indicator.

[2] https://library.modot.mo.gov/RDT/reports/Ri05040/or07005.pdf

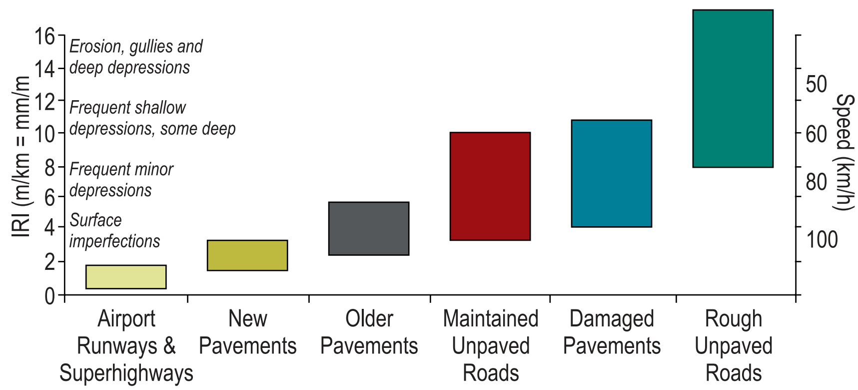


Figure 23: International Roughness Index Scale (adapted from Sayers et al., 1986)

In the Indian context, roughness of a pavement is measured using the Fifth Wheel Bump Integrator or Vehicle Mounted Bump Integrator and is expressed in terms of Roughness Index (RI). As per the Indian Road Congress (IRC) guidelines, a conversion factor ($IRI = 0.0032 [RI]^{0.89}$) is used to arrive at the standard IRI number (IRC SP 16: 2004). The quantitative method to classify road surface into good, average, and poor on the basis of roughness has been explained in Table 36.

Table 36: Classification of road surface into good, average, and poor based on the RI value

Type of surface	RI values (in mm/km) and classification of road surface		
	Good	Average	Poor
Surface Dressing	< 3,500	3,500–4,500	> 4,500
Open Graded Premix Carpet	< 3,000	3,000–4,000	> 4,000
Mix Seal Surfacing	< 3,000	3,000–4,000	> 4,000
Semi-Dense Bituminous Concrete	< 2,500	2,500–3,500	> 3,500
Bituminous Concrete	< 2,000	2,000–3,000	> 3,000
Cement Concrete	< 2,000	2,000–3,000	> 3,000

Source: IRC SP 16: 2004

5.2 Literature review: Roughness index and fuel consumption

There are several studies which indicate that poorly maintained highways have an adverse impact on the performance of vehicles leading to increased consumption of fuel and, therefore, higher emissions. This kind of sensitivity analysis has been mainly done in the US context where efforts have been made to come up with the IRI scale-based fuel efficiency model. A summary of the results estimated by different US-based studies has been presented in Table 37.

Table 37: Summary of sensitivity analyses of the roughness index and fuel consumption/savings for highways in the USA

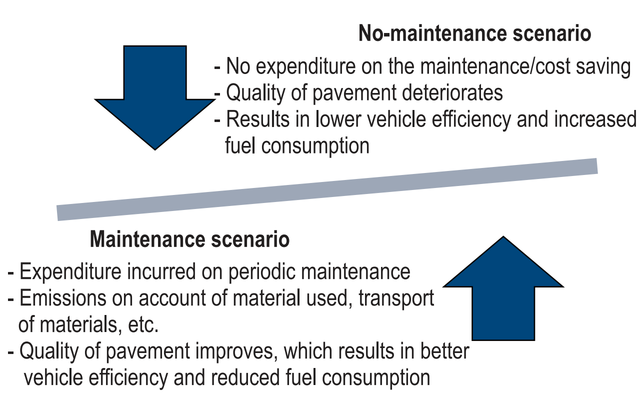
Study	Authors (Year)/ Agency	Methodology	Results	
			Improvement in smoothness	Fuel saving achieved
Pavement Smoothness and Fuel Efficiency: An Analysis of the Economic Dimensions of the Missouri Smooth Road Initiative	Dave Amos (December 2006)/ Missouri Department of Transportation, USA	Fuel consumption/mileage data for diesel-powered truck and gas-powered SUV was collected pre- and post-resurfacing, keeping the distance, vehicle, speed, time of test, tyre pressure, and drivers constant IRI was calculated before and after road resurfacing	53%	2.46%

Study	Authors (Year)/ Agency	Methodology	Results	
			Improvement in smoothness	Fuel saving achieved
Recommended Performance-Related Specification for Hot-Mix Asphalt Construction: Results of the WesTrack Project	Epps, J A, et al. (2002) / FHWA, USA	Two test vehicles were used to collect fuel consumption data before and after re-pavement of the WesTrack facility in Nevada	Every 10% increase in smoothness	Fuel economy increase by 4.5%
An Evaluation of the Relationship between Fuel Consumption and Pavement Smoothness	Jackson, N M (2004) / Florida Department of Transportation, USA	Two test vehicles were used to collect fuel consumption data before and after re-pavement of the road section	Every 10% increase in smoothness	Fuel economy increase by 1.3%

Source: Compiled by TERI

5.3 Relationship between roughness index and fuel consumption: Indian scenario

In the Indian context, an effort has been made to establish a relationship between the quality of road and fuel consumption using TERI's excel-based model for NHs. A methodology has been adopted while approaching this exercise and two scenarios have been considered: (1) a situation where *no periodic maintenance* has been carried out on the NH, and (2) *periodic maintenance has been carried out* to keep a check on the roughness index. Under the first scenario, quality of the road deteriorates over the life of the pavement which has an adverse effect on the fuel consumption and, therefore, on CO_2 emissions on account of vehicular operations. Under the second scenario, periodic maintenance of NHs is undertaken over the life of the pavement so as to achieve smoother roads resulting in better fuel efficiency and reduced fuel consumption.[3] However, there are significant cost implications as well as CO_2 emissions generated on account of periodic maintenance activities in scenario 2 (on account of embodied energy of materials used for the maintenance, movement of materials and people, fuel consumed by equipment, vehicle for movement of workers, and gensets, etc.).



The aim of developing the above-mentioned scenarios is to establish that CO_2 emissions reduction on account of smooth surface during the entire life of the pavement outweighs the emissions associated during the no-maintenance scenario. To establish this, a sample NH project has been selected where periodic maintenance work was undertaken in the recent past and information regarding maintenance cost, traffic numbers, etc. were available from the project site. The findings of TERI's excel-based NH model have been discussed in the following section.

5.4 Impact of good- vs bad-quality roads: A case study of an Indian highway

The Orai–Barah section of NH-24 in Uttar Pradesh, covering a total length of 62.8 km, has been selected as a

[3] https://cshub.mit.edu/sites/default/files/documents/PVIRoughness_v15.pdf

Figure 24: A photograph from the maintenance site

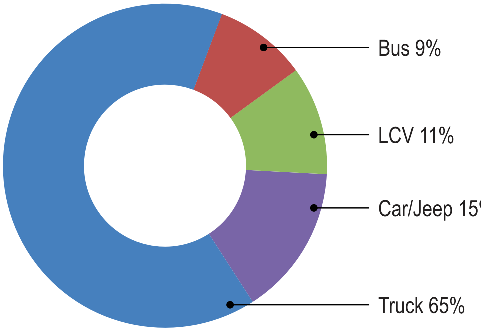


Figure 25: Traffic composition on the Orai–Barah section for 2015–16 (%);

Source: OBIL

case study to demonstrate the effect of maintenance on emissions and cost and emissions savings on account of reduced roughness index or rolling resistance. The construction of the Orai–Barah section, which is a bituminous road, was completed in July 2009 and has a life of 17.5 years. In all, the stretch, during its entire life, will witness three periodic maintenances (17.5 years). The first periodic maintenance of the four-lane highway, which involved milling, tack coating, dense bituminous macadam, bituminous coating, etc., has been recently carried out. The entire cost of the periodic maintenance work has been estimated at Rs 69.2 crore (Rs 691.87 million).

The roughness index was calculated both before and after the periodic maintenance activity which was sourced from the developer (Orai Barah Infrastructure Limited [OBIL]). The data was collected from the Orai–Bhognipur section from km 220.0 to km 255.0 on NH-25/NH-27 and Barah–Bhognipur section from km 421.2 to km 449.0 on NH-2/NH-27. As indicated in Table 38, the roughness index value improved from an average of 2.86 metre/km to 1.815 metre/km.

Table 38: Calculated roughness index before and after periodic maintenance activity (m/km)

Side of stretch	Before periodic maintenance	Post periodic maintenance
Left hand side	2.94	1.82
Right hand side	2.77	1.81

Source: OBIL

As indicated in Figure 25, the share of heavy-duty vehicles (trucks and buses) in the total traffic reported on the Orai–Barah section stands at over 70%. It is to be noted that the stretch is one of the key routes for the transportation of aggregates, mainly from the mining site at Kabrai, Uttar Pradesh.

For the purpose of calculation, the relationship between roughness index improvement and fuel consumption has been taken from the literature (Dave Amos, 2006). The study found that 'a 53% improvement in smoothness which resulted in a 2.46% improvement in fuel efficiency'. The study involved data collection for diesel-powered truck and gas-powered SUV pre- and post-resurfacing, keeping the distance, vehicle, speed, time of test, tyre pressure, and drivers, constant. The number is relevant for the Orai–Barah section also, as it witnesses high volume of heavy-duty and light-commercial vehicle traffic. Also, the percentage increase in roughness index post-periodic maintenance for the stretch considered under the international study and that under the Orai–Barah section is comparable. Also, both the highways under consideration have bituminous layer so that the highway types are comparable.

The impact of periodic maintenance on the Orai–Barah section on fuel savings on account of reduction in rolling resistance is given in Table 39. As a result of periodic maintenance, the roughness index of the Orai-Barah section improved from 2.9 m/km to 1.8 m/km activity resulting in total fuel savings of 4.55 lakh litres (petrol and diesel). Taking the average yearly price of petrol and diesel at Rs 62.62 per litre[4] and Rs 50.86 per litres[5] during 2016, the total savings in fuel costs on account of improved efficiency of vehicles running on the stretch post periodic maintenance comes to around Rs 2.03 crore in one year alone. As per TERI analysis, the reduction in both energy consumption and CO_2 emissions on account of the improved Orai–Barah section for the year 2016 is around 1.7%.

[4] https://www.iocl.com/Product_PreviousPrice/PetrolPreviousPrice.aspx

[5] https://www.iocl.com/Product_PreviousPrice/DieselPreviousPrice.aspx

Table 39: Fuel and cost savings on account of improvement in roughness index due to periodic maintenance (for one year)

Fuel	Fuel consumption before periodic maintenance (kl)	Fuel consumption after periodic maintenance (kl)	Fuel savings (kl)	Cost savings (Rs lakh)
Petrol	592.18	586.14	6.04	3.78
Diesel	23,414.56	23,022.46	392.10	199.42
Total	24,006.74	23,608.60	398.14	203.20

kl: Kilolitres; Source: TERI Analysis

Fuel savings and fuel cost savings estimation for 5 years post the first periodic maintenance of the Orai–Barah section has been attempted by TERI. It is, however, proposed that a more detailed/technical study is conducted for Indian conditions to establish the relationship between improvement in riding quality/roughness index and fuel efficiency/fuel saving.

For the estimation purpose, traffic growth is likely to be 5% and the growth in fuel price at 4% during the fifth year of operations (Pradeep A. and Shruti T., 2015). With regard to the deterioration factor, it is assumed that during the fourth and fifth years post periodic maintenance, IRI would increase to 3 m/km leading to a decline in fuel efficiency by 1.7% for LCVs/HCVs/buses and about 4.5% for passenger vehicles/cars (Chatti, 2012). IRI has been assumed to be constant for the first three years.

Cost savings on account of periodic maintenance: Between the first and second periodic maintenance of the Orai–Barah section, it is estimated that a total of Rs 6.6 crore is saved on account of better riding quality during the first three years and a loss of Rs 6.2 crore on account of an increase in the roughness index (thereby, lower fuel efficiency) during the fourth and fifth years. The net benefit on account of periodic maintenance stands at a marginal amount of about Rs 40 lakh under this project.

CO_2 emissions savings on account of periodic maintenance: Based on the assumptions mentioned above as well as emission coefficients, CO_2 emissions savings have been estimated for years between the first and second periodic maintenance. A total of 3,400 tonnes of CO_2 was saved during the first three years of periodic maintenance, while 2,800 tonnes of CO_2 was emitted during the fourth and fifth years due to the deterioration effect leading to net emission savings of 600 tonnes over 5-year period. Figure 26 indicates a year-wise CO_2 emissions savings/loss on account of improved/deteriorated surface quality for the Orai–Barah section.

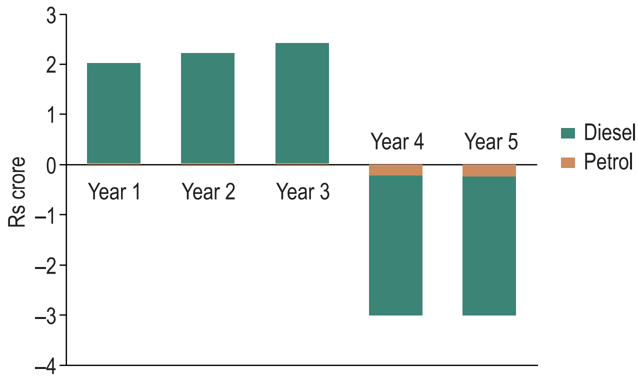


Figure 26: Projected fuel cost savings/loss on account of improved/deteriorated surface quality post periodic maintenance of the Orai–Barah section

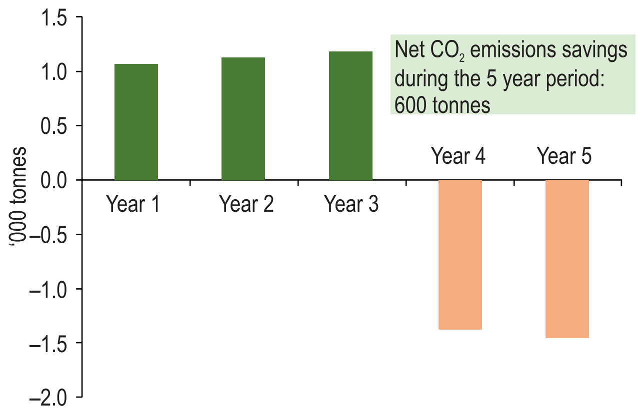


Figure 27: Projected CO2 emissions savings/loss on account of improved/deteriorated surface quality post-periodic maintenance of the Orai–Barah section

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7

Annexures

Annexure1: Carbon Footprint Estimates in International and Indian Studies

Table 40: Past carbon footprint (life cycle carbon emissions) estimates for highway projects from international and Indian studies

Name of Study	Design Life of the Road Considered	Pavement Typology	CO_2 Emissions/Embodied Energy During the Three Phases of Highway's Life		
		Construction	Maintenance	Operations	
International Studies					
Life Cycle Assessment of Road: A Pilot Study for Inventory Analysis (Stripple, 2001)	40 years	Asphalt pavement	23 TJ/km (Embodied Energy) [Construction, maintenance and operations data combined value was available]		
		Concrete pavement	27 TJ/km (Embodied Energy) [Construction, maintenance and operations data combined value was available]		
Carbon Footprint for HMA and PCC Pavements (Mukherjee, 2011)	15 years	Asphalt pavement	511.27 (MT CO_2Eq./year/lane mile) [Construction, maintenance and operations data combined value was available]		
The Greenhouse Gas Emission from Portland Cement Concrete Pavement Construction in China. (Feng Ma, 2016)	Not indicated in the study/ paper	Concrete pavement	2,053.83 (ton CO_2/lane km)	X	X

Indian studies					
Methodology for Estimating Carbon Footprint of Road Projects: Case Study India (Asian Development Bank, 2010)	22 years	Asphalt pavement [NH (MP/UP): East West Corridor; 4 lane]	24 (ton/lane km/year)	2.8 (ton/lane km/year)	826.7 (ton/lane km/year)
Life Cycle Analysis of Transport Modes (TERI, 2012)	30 years	Asphalt pavement [Rohtak-Bawal NH-71; 4 lane]	28.7 (ton/lane km/year)	X	X
		Asphalt pavement [Delhi-Agra NH-2; 6 lane]	X	5.97 (ton/lane km/year)	X

SH: State Highway; MP: Madhya Pradesh; UP: Uttar Pradesh

Annexure 2: Measuring Carbon Footprint in India

An existing methodology for estimating the total life cycle CF of road projects in India was developed by the Asian Development Bank (ADB) in partnership with TERI in 2010. The possible sources of direct and indirect CO_2 were identified under the study under the three heads, namely, road construction phase, road operation phase, and road maintenance phase (Asian Development Bank, 2010). The various sources of carbon emissions captured for the ADB methodology are given in Table 41. A detailed carbon estimation model was then prepared for estimating CF of the total ADB funded road projects in India. ADB road portfolio was classified into NHs in flat terrain, state highway (SH) in flat terrain, SHs in hilly terrain and rural. CF for sample projects (selected under the four heads) was then calculated and extrapolated to arrive at an average annual value of CF of the ADB's road sector portfolio in India.

The methodology for carrying out LCA of Indian roads was further modified by TERI for carrying out the study on the LCA of transport modes (TERI, 2012), which took into account the various life stages of the different modes of transportation, such as construction of fixed infrastructure, manufacture of rolling stock, movement of rolling stock for transportation of people/goods, maintenance of rolling stock, maintenance of fixed infrastructure, etc. A bottom-up approach was adopted after defining the system boundary. In addition to NHs (construction of the Rohtak–Bawal NH (NH-71) and maintenance of the Delhi–Agra NH were studied), this study also estimated the LCA of urban road, Bus Rapid Transit System (BRTS), and Metro Rail Transit System (MRTS) and a long-distance passenger railway. System boundaries were established in line with the several international applications of LCA in transport sector to ensure that the implementation of the LCA methodology was in line with ISO 14000 framework for carrying out LCA. Typical projects were selected for various modes to estimate the life cycle impacts over a period of 30 years. India specific spread sheet model was to developed to carry out LCA for transport sector.

The key elements that have been considered in this LCA framework and included in the data collection process (*questionnaire attached*) are as follows:

Table 41 Emission sources considered for estimating carbon footprint in methodology developed by ADB

Road Construction Phase	Road Operation Phase	Road Maintenance Phase
1.1 Construction materials • Embodied carbon in construction materials • CO_2 emissions due to transportation of construction materials to/from site	2.1 Fossil fuels • Embodied carbon in fossil fuels • Direct emissions due to combustion of fuels in vehicles	3.1 Construction materials • Embodied carbon in construction materials • CO_2 emissions due to transportation of construction materials to site
1.2 Fossil fuels and electricity • Embodied carbon in fossil fuels • Direct emissions due to combustion of fuels in machinery and vehicles used on site • Diesel used in generators for producing electricity • Electricity used from the grid		3.2 Fossil fuels • Embodied carbon in fossil fuels • Direct emissions due to combustion of fuels in machinery and vehicles used on site
1.3 Removal of vegetation • Direct emissions due to combustion of fuel wood		
1.4 Construction machinery and vehicles		

Table 42 Scope of LCA framework: Construction and maintenance stages

Components of LCA	Included	Remarks
Construction Phase		
Production of construction materials		
Embodied energy and CO_2 of construction materials	Y	India specific coefficients from AEI (2009) International values from Hammond and Jones (2008)
Indirect energy consumption and CO_2 – Energy consumed for constructing buildings, manufacturing machinery, etc. used for production of materials	N	Rational for not including Capital assets- common infrastructure used for producing construction materials for several projects; Embodied energy cannot be included in one project
Transportation of construction materials		
Direct CO_2 due to fuel consumption by vehicles transporting construction materials	Y	India specific CO_2 emission factors from MoEF (2010) and ARAI (2007)
Embodied energy and CO_2 of fuels used	Y	Indian and international coefficient values from TERI (2010) and Edwards et al (2006)
Embodied energy and CO2 of trucks/vehicles used	N	Capital assets; common to several projects/ non construction activities
On-site impacts		
Direct CO_2 due to on-site fuel consumption (by construction machinery)	Y	India specific CO_2 emission factors from MoEF (2010) and ARAI (2007)
Embodied energy and CO2 of fuel used (by construction machinery)	Y	International coefficient values from TERI (2010) and Edwards et al (2006)
Indirect energy consumption (energy consumed for manufacturing construction machinery/equipment used on site)	N	Rational for not including Machinery/equipment are common to several construction projects – need to proportionately distribute embodied energy to all projects where they are used – may not be significant per project
Vegetation removal – carbon sequestration potential lost	Y	Didn't need to calculate due to compensatory vegetation being planted
Vegetation removed – use of some portion of removed trees as fuel wood	Y	Estimating the quantum of fuel wood from trees cut and then, applying its CO_2 emission factor
Maintenance Phase		
Direct energy consumption and CO_2 (tailpipe and embodied) emissions from vehicles moving on the transport corridor	Y	Energy consumed per passenger km estimated using actual fuel consumption data for different modes; India-specific CO_2 emission factors used
Indirect energy consumption and CO_2 i.e. energy consumed and CO_2 emitted due to manufacturing and maintenance of rolling stock	Y	Data estimated for USA considered
Maintenance of fixed infrastructure		
Activities associated with annual and periodic maintenance works: • Material consumption (embodied energy and CO_2) • Energy use on site	Y N	Only material consumption considered in maintenance activities Energy efficiency levels in future assumed to remain same as today

- **Raw material extraction, processing, transport and manufacture:** The various materials that were considered were:
  - Aggregate/ base material
  - Bitumen
  - Bitumen emulsion
  - Cement
  - Steel
  - Earth (cut and fill)
  - Steel reinforcement
  - Concrete (offsite mixing)
  - Mix material/ hot mix asphalt (offsite mixing)
  - Bricks
  - Water
  - Limestone dust
  - Admixtures
  - Paint
  - Primer
  - Concrete pouring compound
  - Joint sealant
  - Polymeric synthetic fibers
  - Materials for formwork
  - Pre-cast slabs, stone slabs
  - Others

The quantity of materials collected included materials required for construction of pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc. The embodied carbon of these materials was taken into account. The study did not take into consideration separate embodied carbon values for various grades of cement, aggregate sizes, grades of bitumen or radii of steel enforcement while estimating carbon footprint. Single embodied carbon values were taken into consideration for a particular material. Street furniture like signages, street lights, toll gates, bus stops, road delineators, etc. were also considered.

- **Energy consumption and direct emissions during transportation of construction worker/ personnel/materials/waste to and from construction site:** The direct CO_2 emissions due to fuel consumption by the transport vehicles and embodied energy of carbon in these fuels were considered. The amount of emissions from transportation of materials were calculated using data on:
  - Distances (lead) travelled,
  - Quantity transported, and
  - Modes used for transportation
- **On-site energy usage:** Key fuels consumed on-site included
  - Diesel (Vehicle and machinery and usage and use by generators)
  - Light Diesel Oil (LDO)
  - LPG
  - Electricity
  - Kerosene
  - Natural gas
  - Biomass

Data on these was collected and included in estimation of CO_2 emissions.

- **Operational stage:** Traffic estimates or various years during the entire design life of the road were taken into consideration. The various modes considered included
  - Cars
  - Two wheelers
  - Taxis
  - Jeeps
  - Buses
  - Mini buses
  - LCVs
  - HCVs
  - Others

The embodied carbon of the fuels used by these vehicles traveling along a particular section and the corresponding carbon emissions arising from the direct fuel combustion were taken into consideration. Material and energy consumption for manufacture and maintenance of rolling stock was not taken into account. The operational stage did not also cover energy/ electricity usage by street lights, toll plazas, etc.

- **Consumption of materials and energy for annual and periodic maintenance:** Key annual routine maintenance and periodic maintenance works were considered (Table 43).

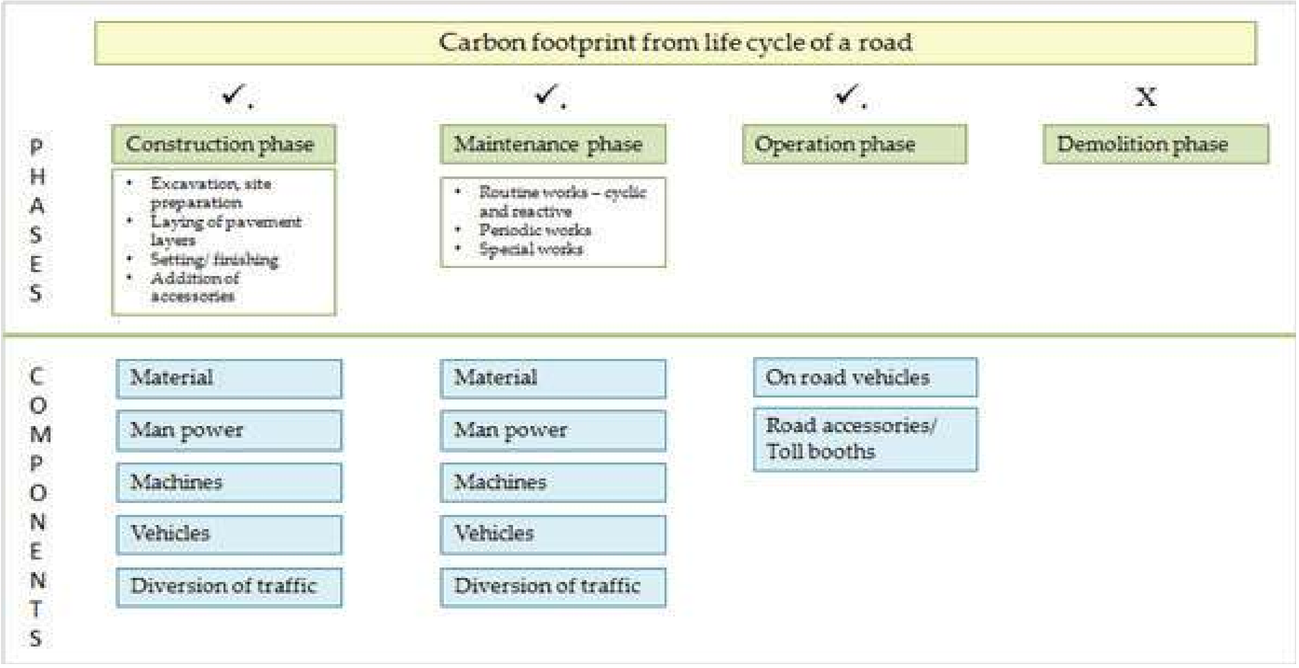
Table 43: Key Annual/routine and periodic maintenance works and materials used

Annual maintenance	Periodic maintenance
• Patch work in case of bitumen roads, replacement of panels in case of concrete roads • Crack sealing, • Painting, • Repairing of road furniture, • Median fencing, etc.	Relaying of highways Painting Other renovation works
Materials used during the maintenance works: Bitumen, Mix material/Hot mix asphalt, Aggregate/base material, Cement, Sand, Fill, Paint, Primer, Water, and Others	

Material and energy consumption for manufacturing/constructing capital assets like the machinery used for construction, trucks used for transportation of materials, factories/industries/retail facilities used for manufacture/sale of construction materials, etc. were not included in the LCA scope on account of their insignificant contribution to a single project. The CO_2 sequestration potential lost due to removal of vegetation was not accounted for as the road contractors were required to plant equal number of new trees in order to compensate the tree loss; it makes up for the carbon sequestration potential lost on account of trees cut during construction. Also, one of the challenges with regard to this was that in a number of the responses received for the representative highways, the details/data related to felling to tress was not provided.

Framework for CF calculations for Indian Highways

The framework developed for estimating carbon emissions from the highway sector in India focuses on the various phases of lifecycle of a highway and the various components that are involved in each phase. The phases that are considered under the scope of this study are construction phase, maintenance phase and operation phase. The demolition phase has not been accounted for as highways in India are rarely demolished; they are usually upgraded or abandoned. Under the construction phase, excavation, site preparation, laying of pavement layers, setting/finishing and addition of various road accessories would be considered. Under maintenance phase, routine works (cyclic and reactive) and periodic works and special works are taken into account.



Construction stage

Site preparation activities
- Carbon sequestration potential lost due to removal of vegetation
- Carbon emissions from vehicles and equipment used like trucks, JCBS, bulldozers, trailers, tractors, etc.

Construction process
- Transportation of construction material
- Embodied carbon of material
- Carbon emissions from vehicles and equipment used like trucks, JCBS, bulldozers, trailers, tractors, etc.
- Indirect carbon emissions from site office activities, labour camps, etc- electricity , generators

Within boundary

- Embodied carbon of the machinery and equipment used

Outside boundary

Operational stage

Current

Embodied carbon of vehicle and fuel

Vehicular emissions

Traffic load on highways

Vehicular composition

- Passenger traffic – cars, two-wheelers, 3-wheelers, buses
  - Broad vehicle classification , fuel technology, etc.
- Freight traffic – HCVs, LCVs
  - Axle loads, fuel technology

Within boundary

- Driving behaviour
- Geometric design of road section
- Level of service of road (Traffic congestion)

Outside boundary

Projections

- Vehicular emissions
  - Projected traffic load on highways
    - Projected vehicular composition

Within boundary

- Improvement in driving behaviour
- Improvement in road geometry
- Improved level of service of road

Outside boundary

Maintenance stage

- Transportation of construction material
- Embodied carbon of material
- Carbon emissions from vehicles and equipment used like trucks, JCBS, bulldozers, trailers, tractors, etc.
- Indirect carbon emissions from site office activities, labour camps, etc- electricity , generators

Within boundary

- Embodied carbon of the machinery and equipment used
- Carbon emissions due to diversion of traffic/ traffic congestion due to blockage of highway etc

Outside boundary

Annexure 3: Questionnaires for Component 1 of the Study

Questionnaire for Collecting Construction Data for a National Highway Project

About the Project

Name of the project:			Date:
City/State:			
Road start and end points:	From-	To-	Total distance between the two points (km):
Road length constructed as on date (km):	Entire length constructed ☐ ☐ Partially constructed Length of road constructed till date _______km* *Please provide data for the constructed length of road, as on date		
Construction duration:	Start date- End date/expected end date-		
Nature of construction: Green field/ up gradation(lower lanes to higher number of lanes) – Please specify details			
Pavement type	Bitumen ☐ Cement ☐ Composite ☐ Other_________________		
Design life of pavement (years):			
Cross-section details	ROW: _______m, No. of lanes :_________, Carriage way width ________ m, Divided ☐ /undivided ☐, median width ________ m, shoulder______ m, service road _________m Drainage: Type ________________ Diameter ____________; Other details________________________		
Other	Is project DPRC available: Yes ☐ No ☐ ; If yes, please share DPR		
Name of officer in charge of project with contact details			
Name of Contractor with contact details			

Design considerations

- Specify the IRC code followed for construction _______________
- Pavement design details:

Layer	Thickness (mm)	Material composition	Quantity consumed for constructing per km of highway
		______________; ______________; ______________;	______________; ______________; ______________;
		______________; ______________; ______________;	______________; ______________; ______________;
		______________; ______________; ______________;	______________; ______________; ______________;
		______________; ______________; ______________;	______________; ______________; ______________;
		______________; ______________; ______________;	______________; ______________; ______________;
		______________; ______________; ______________;	______________; ______________; ______________;

Information on material and energy consumption during pre-construction activities/utility shifting

Construction material/ Fuel	Quantity used (tonnes/ litres)	Sourced from where		Mode used for transporting material/fuel from source					
		(location name)	Distance from site (km)	Vehicle type	No. of trips	Average loading (tonnes/ litres)	Fuel type	Fuel efficiency	Avg. idling time while loading/ unloading (hrs)
Materials									
Fuel consumed									
Diesel									
Petrol									
LDO									
Others (please specify)									

Information on street furniture/ road accessories

Type of street furniture used/will be used (please specify the road length for which information is being provided)	Quantity per km (number, etc.)	Primary materials of which street furniture is made (steel, aluminum, etc.)	Weight of primary materials per fixture (if available)	If weight of primary materials per fixture is not available, then, give key dimensions/ features of a typical fixture (height, area, diameter, type)	Manufacturer	Source from where street furniture is/was brought						
						Place	Distance from site/ lead (in km)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/ unloading (hours) (when engine is on)
Signages												
Street lights												
Toll gates												
Safety barriers												

Bus stop shelter (if any)												
Road delineators												
Traffic signals												
Others: (Specify)												

Information on on-site electricity and fuel consumption (for the road length constructed)

Electricity consumption	
1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, labour camps, etc.?	Total electricity purchased from electricity distribution company/ state electricity board (as on date): _________ (Unit ______) (In case month wise-data is available, please fill details in the Annex 1) Which company? :____
2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details.	No. of generators used: _________ Fuel type used in generators: ______________________________________ Total quantity of each fuel type used in generators (as on date): Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ Fuel_______ Quantity_______ Unit_____ (In case month wise-data is available, please fill details in the Annex 1) What is the average daily use of generators?: ______hours
Consumption of fossil fuels and biomass	

1. Type of vehicles/ machinery used on-site during construction	Type	Number	Fuel type	Average fuel efficiency of vehicle/machine (l/km or l/hr) please specify
2. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)? (excluding use of fuel in generators) (In case month wise-data is available, please fill details in the Annex 1)	Fuel	Quantity	Unit	
	Diesel			
	Petrol			
	CNG			
	Furnace oil			
	LDO			
	Kerosene			
	LPG			
	Natural gas			
	Biomass			

Information on Transport of fuel

Fuel	**Total quantity**	**Source from where fuel was brought**					
		Place	**Distance from site/ lead (in km)**	**Vehicle type (Truck, tanker, etc.)**	**Average loading on vehicle**	**Fuel type of vehicle (diesel, CNG, etc.)**	**Fuel efficiency (km/l) of vehicle**
Diesel							
Petrol							
CNG							
Furnace oil							
LDO							
Kerosene							
LPG							
Natural gas							
Biomass							

Information on Personnel movement - travel of construction staff/labour

Staff/labour	No. of staff/ labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (km)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Are the vehicles owned by the contractor? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						
Equipment operators						

Information on vegetation removed

Vegetation removed Was there any removal of vegetation during construction phase? If yes, then please give the details.	No. of trees removed/cut during construction or hectares of forest area cut during construction _______ What were the main species removed? ______________________________ What was the average age of trees cut? What was the average width of trees cut? What was the average height of tress cut? Were these trees burnt on site, or given to nearby villages to be used as fuel wood or given to forest department? ______________________________ Are there any photographs of the site before construction began showing the vegetation/tree cover? Please share the photographs. Was any replantation done to compensate for the trees cut? Were you required to seek Forest Department's/Ministry of Environment's clearance for road construction? If yes, is it possible to share the reports/documents submitted for clearance?

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(To be filled in case, the contractor has month-wise numbers)

Month, Year	Electricity purchased from power distribution company (specify unit)	For Electric generators only					Total fuel consumption for all on-site construction activities, except use in electric generators									
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Questionnaire for collecting maintenance data for National Highways

Questionnaire for collecting maintenance data for National Highways

About the Highway

Name of the project			Date:
Road section maintained: (Road start and end points)	From-	To-	Total distance between the two points (km):
City/State:			
Pavement type	Bitumen Cement Composite Other________________		
Cross-section details	ROW: _______m, No. of lanes :_________, Carriage way width ________ m, Divided /undivided , median width ________ m, shoulder______ m, service road _________m Drainage: Type ________________ Diameter ____________; Other details_______________________		
When was the road constructed? (Completion date of road construction)	_____Month _____ Year		
What is the expected life of the road pavement?			

Routine maintenance of Highway (ordinary repairs)

1. What are the key routine maintenance activities? [e.g. patch repairs, crack sealing, repairing shoulders, painting (signs, km stones, road markings, etc.), vegetation removal]					
2. For routine maintenance activities, please share details for one year maintenance work as indicated below.					
2a. Material consumption					
Materials used for routine maintenance (for 1 year)	**Quantity used in one year**	**Source from where construction material/fuel was brought and mode of transportation**			
		Place	**Distance from site/ lead (in km)**	**Typical vehicle type (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen					
Mix material/Hot mix asphalt					
Coarse aggregate					
Fine aggregate					
Cement					
Sand					
Ready mix concrete					
Paint					
Primer					
Water					
Base material					
Soil					
Others					
2b. Energy consumption (In case month wise-data is available, please fill details in the Annex2)					
Electricity					
Diesel					
Petrol					
Kerosene					
Furnace oil					
Biomass					
Others (please specify)					

3 Information on Personnel movement - travel of construction staff/labour

For, routine maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	No. of staff/ labour involved in a year	No. of days in the year when maintenance work is carried out	Typical mode of travel (for coming to construction site)	Average distance travelled to reach site (km)	Remarks
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Annex 2

Month-wise electricity and fuel consumption for routine maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Periodic renewal/maintenance of Highway

(Renewal coat to the wearing course/surface done periodically at predetermined frequency)

1. What is the frequency of periodic renewal/maintenance i.e. putting renewal coat to the wearing course/surface?	________years				
2. Who carries out the periodic maintenance?	NHAI or Contractor				
3. Please give details for one periodic renewal/maintenance work on the road					
3a. Material consumption					
Materials used for 1 full periodic maintenance work (Confirm the length of road for which this work was carried out)	**Quantity used**	**Source from where construction material/fuel was brought and mode of transportation**			
		Place	**Distance from site/ lead (in km)**	**Typical vehicle type used (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bricks					
Coarse Aggregate					
Fine aggregate					
Water					
Ordinary Portland Cement 53 Grade					
Ordinary Portland Cement 43 Grade					
Portland-Pozzolana Cement					
Portland Slag Cement					
Chemical Admixture					
Fly Ash					
Granulated Blast Furnace Slag					
Silica Fume					
Ready mix concrete*					

Steel reinforcement					
Other steel					
Concrete curing compound					
Pre-Molded Joint Filler					
Joint Sealing					
Steel or polymeric synthetic fibers					
Bitumen/ Tar					
Cationic bitumen emulsion					
Ready-made Premix material not mixed at project site if any (specify whether hot/cold/warm)*					

** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*

Materials used for 1 full periodic maintenance work (Confirm the length of road for which this work was carried out)	**Quantity used**	Source from where construction material/fuel was brought and mode of transportation			
		Place	Distance from site/ lead (in km)	Typical vehicle type used (Truck, tempo, etc.)	Fuel type of vehicle
Paint					
Primer					
Materials for formwork					

In case, NH section has sidewalk/ pavement (in urban areas), then: - Precast cement concrete slabs - Stone slabs - Others					
Others (if any)					
3b. Energy consumption (In case month wise-data is available, please fill details in the Annex 3)					
Electricity					
Diesel					
Petrol					
Kerosene					
Furnace oil					
Others					

**Is any of the material that is removed from the wearing course recycled?*

4. Information on Personnel movement - travel of construction staff/labour

For, periodic maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	No. of staff/ labour	No. of days in which work was completed	Typical mode of travel (for coming to construction site)	Average distance travelled to reach site (km)	Remarks
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority?
Construction labour					Is the fuel consumption of the vehicles included in numbers provided above?
Workmen					
Equipment operators					

5. Maintenance of Highway Assets

- What is the frequency of maintenance of the following highway assets:
    - Storm water Drainage ________________
    - Street lights ____________________
    - Roadside vegetation ________________________
    - Safety barriers ________________________
    - Others

Annex 3

Month-wise electricity and fuel consumption for periodic renewal/maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Questionnaire for collecting operation data for National Highways

Information on expected traffic on the road

- If traffic volume counts have been carried out on the road stretch, please share the vehicle numbers from the survey
- Please share the DPR of the project. We need the traffic estimates for the entire design life of this road/road section from DPR/project feasibility report. Do these traffic estimates include the induced traffic effect? Please fill details
- In case, you don't have traffic estimates, please share the expected growth rate for vehicles, if available.

Traffic estimates for the entire design life of this road/road section from DPR/project feasibility report

Year	Cars	Two wheelers	Taxis	Jeeps	Buses	Mini buses	LCVs	HCVs	Others

Traffic Operations and volume

Provide Annual Average daily traffic (AADT) in PCUs- differentiated by vehicle categories (For the last 5 years)

Year	Cars	Two wheelers	Taxis	Jeeps	Buses	Mini buses	LCVs	HCVs	Others

Peak traffic information

Peak traffic period of the year (Months/ Weeks) (For the last 5 years)

Year	Peak traffic period of the year (Months/ Weeks)	Average Daily Traffic (ADT) recorded during the peak periods (in PCUs)

Month-wise electricity for use in consumption during operation phase (for toll booths, street lights, traffic lights, etc.)

(In case month-wise numbers are available)

Month, Year	Electricity (quantity in KWh)

Annexure 4: Other Interventions that have a Positive Impact on CO_2 Emissions Reduction

4.1 Planning and design stage

4.1.1 Alignment and bypass selection

The selection of route/alignment or any bypass of a greenfield/existing highway is a complex task as various engineering, social and environmental parameters are involved, which need to be assessed and evaluated before finalizing the alignment. Primarily the '*Highway alignment is influenced by terrain and factors such as the cost of right-of-way, land use, waterways that may require expensive bridging, existing roads, railroads, and subgrade conditions* (Road design , theory and concepts)[1]. Firstly, several typical *preliminary maps are drawn showing various alignments. Selection of an alignment is a trial and error process, as the proposed alignments are checked for compliance with the horizontal and vertical control criteria. The selection of the final alignment is based on a comparison of costs* as well as *environmental and social impacts*' (Road design , theory and concepts).[2]

For any greenfield or bypass to an existing highway, considering environmental impacts and the CO_2 emissions in deciding route/alignment of any highway is gaining importance among road designers. If this factor is assessed in the planning stage of route selection, it will help in reducing considerable amount of CO_2 emissions, which otherwise may be emitted during construction/operations of highway. Few broad points that could be considered while selecting final alignment from various alignment options are listed below. Alignment selection based on these considerations can help in reducing overall carbon footprint of highway for the entire life.

a. The construction materials such as aggregate (from quarry) and natural sand to have least leads for the selected highway alignment among all the alignment options, so that fuel consumption and resultant CO_2 emissions from trucks fleets for haulage of these materials are minimum.

b. The alignment to pass as close as possible to the nearby towns/city areas or any other national/state highways so that transportation of materials such as cement, concrete and steel consumes less fuel and emits less tailpipe emissions from transport vehicles due to good access or approach roads close to the alignment.

c. If there are two options, one - having flatter gradient and other having steeper gradient, the flatter gradient option can be considered even though it may be slightly costlier than steeper gradient option. The fuel consumption and CO_2 emissions will be less from the vehicles on flatter gradient.

d. If there are two options, one- having flatter curve and other having sharper curve, the flatter curve option can be considered even though it may be slightly costlier than sharper curve option. The fuel consumption and CO_2 emissions will be less from the vehicles on flatter curves.

e. The alignment to pass through the area where bitumen/concrete/WMM plant can be set up as near as possible to reduce their transport related fuel consumption and emissions.

f. The availability of water and borrow soil should also be approximately assessed in planning stage so that these materials have least possible haulage during construction.

g. The final alignment should also have least possible removal of vegetation, as it will help in saving loss of carbon sequestration potential.

4.1.2 Detailed investigations and analysis of alternate materials in DPR stage

Detailed Project Report (DPR) stage is the most important stage with regard to adoption of highway design and construction technology. It is the first stage where CO_2 emissions reduction interventions can be investigated and evaluated. Following interventions

[1] http://www.webpages.uidaho.edu/niatt_labmanual/chapters/roadwaydesign/theoryandconcepts/RouteSelectionAndAlignment.htm ; last accessed on

[2] Ibid.

for reduction of carbon emissions are gaining interest among design consultants and can be considered/ adopted during preparation of Detailed Project Reports.

- Detailed surveys and investigations along with relevant lab tests of alternate construction materials (new/waste/recycled) available in the project influence area in order to explore and adopt green alternate materials, if found feasible and suitable.
- Along with alternate construction materials, new green technology suitability with regard to project location can be investigated, e.g. the cold mix technology and the emerging warm mix technology can be considered at this stage. The foam bitumen mix technology[3] which helps in reclaiming old asphalt and recycling can also be taken into consideration.
- Use of soil stabilization is an emerging and innovative technology and needs to be explored during design stage. Soil stabilization includes addition of 1% to about 6% of stabilizer such as cement, lime, fly ash and other commercially available products to the soil and marginal aggregate; the stabilized soil and aggregate can be used as subgrade and sub-base/base layers, respectively. By using the stabilized subgrade or sub-base/base layer, the thickness of pavement layer (mainly asphalt layers) can be reduced, which in turn can help in reducing the carbon emissions from pavement construction.

There are large number of alternate materials (new/ waste/recycled) and green technologies, which can be studied and evaluated during the design stage. The details of alternate and green construction materials (new/waste/recycled) and innovative green technology are presented and elaborated later in this Chapter**.**

In addition to consideration of the use of alternate material and green technologies, environment friendly geometric designs also need to be considered during the DPR stage.

Environment-friendly highway geometric design is emerging as one of the strategies to reduce adverse impacts of fuel consumption and GHG emissions due to vehicle operations. However, there are not many standards and specifications, which include vehicle fuel consumption and emission reduction strategies by means of highway geometric design improvements. '*There has been much progress in the development of vehicle engine technology and alternative fuels to reduce the adverse impact of highway transportation on the environment. However, the research regarding the reduction of the adverse impact through highway design is still in its infancy*' (KO, Incorporating Vehicle Emission Models into the Highway Design Process, 2011)

A few studies have been conducted internationally to estimate the 'environmental impacts, by means of fuel consumption and emissions, of various highway geometric design conditions on the vertical grades as well as for horizontal and vertical crest curves that could be included in the highway design process' (KO, Incorporating Vehicle Emission Models into the Highway Design Process, 2011). These studies suggest that highway geometric design improvements could be effective in reducing vehicle fuel consumption and emissions. For example, (K.Boriboonsomsin and M.Barth , 2009) and (Hesham A. Rakha et al., 2013)conclude that a vehicle consumes more fuel and produces more emissions when roadway grades are steeper because of the greater demand on the vehicle's power. They estimate that a vehicle consumes 15 to 20% more fuel on an uphill route at a 6% grade followed by downhill route at a 6% grade than on a flat route.

Generally, the method followed to study the impact of highway geometric design on fuel consumption and carbon emissions is by generating '*second-by-second speed profiles using the speed prediction models and non-uniform acceleration/deceleration models, and then extracting the fuel consumption and emission rates based on vehicle specific powers and speeds using recently developed motor vehicle emission simulator (MOVES)*' (KO, Incorporating Vehicle Emission Models into the Highway Design Process, 2011)[4]. Such models can be developed and used for understanding the impact of highway design on fuel consumption and carbon

[3] The bitumen foaming is a technique of adding water to hot bitumen, and thereby causing a temporary expansion of the hot bitumen, in order to enable coating of cold aggregate

[4] MOVES is the US EPA's state-of-the-art tool for estimating fuel consumption and emissions from vehicle operations. It allows users to analyze motor vehicle emissions at the national, regional, and project levels, using different levels of input data. (https://www3.epa.gov/otaq/models/moves/documents/420b12028.pdf; last accessed on)

BOX-8: EFFECT OF SPEED AS WELL AS GEOMETRIC DESIGN ON THE CO2 EMISSIONS

An extensive research study for evaluating the improvement of highway geometric design which helps in reduction of fuel consumption and CO_2 emission was done under the study 'Incorporating vehicle emission models into the highway design process' (KO, Incorporating Vehicle Emission Models into the Highway Design Process, 2011). A brief description of the conclusion of this study is as follows:

For Vertical Grade Design:

The design vehicle (i.e., a typical heavy duty truck) consumed 14% more fuel and produced up to 15% more emissions with the initial speed of 10 km/h to 110 km/h on the vertical grade. Higher initial speeds in the grade design would be beneficial in reducing fuel consumption and emissions.

- The truck consumed more than six times fuel on a nine% grade than a flat grade during the trip.

For Vertical Crest Curves Design:

- Vertical curve designed with smaller K-values (the below-minimum standard design) is shown to have increased the fuel consumption and emissions by nine%; standard K-values provided sharper changes on the curves than the minimum standards. The increased vehicle engine power on the sharpened curves lead to more fuel usage and emissions.

Horizontal Curves Design:

- The amount of CO_2 emitted during a trip was minimal when speeds stayed in the range of 70 to 80 km/h.
- The reduced speeds due to sharp radius on the curve played a role in saving fuel and hence reducing emissions. On the other hand, speeds of 90 and 110 km/h without any speed reduction on those curves with radius designs greater than or equal to the minimum standards actually increased overall fuel consumption and emissions. The emissions were greater when driving on a curve where acceleration and deceleration occurs.

Source: KO, (2011)

emissions and for selecting geometric designs that have the potential of reducing fuel consumption and CO_2 emissions. Box 8 shows the effect of speed as well as geometric design on the CO_2 emissions

4.1.3 Innovative pavement design considering carbon emissions of selected materials

Best practices for pavement design that can help in reducing CO_2 emissions from highway construction are discussed below.

Optimization and alternate pavement composition: Design of pavement by optimizing pavement layer's materials, the related mix compositions and reducing pavement layer thickness can help in reducing the carbon emissions from construction. While making a pavement design proposal, besides the conventional flexible and rigid pavement options, innovative approaches, such as, pavement composition with one or more stabilized materials can also be explored. Moreover, optimization of both the use of materials and pavement cross sections that meet performance requirements while achieving environmental and economic benefits can be carried out. In this regard, a study on comparison of GHG emissions of various pavement compositions has been conducted in India for a case study National Highway (Dr P. K. Reddy Nanda and N Madhava, 2011). In this study, four types of pavement are considered - Conventional flexible pavement, Composite pavement having subgrade treated with cement, Composite pavement having subgrade treated with non-cement stabilizer and Conventional Cement Concrete pavement. One km road section of four lane divided carriageway is considered with 1.5 m paved and 2.0 m earthen shoulders.[5] The pavement compositions

[5] Assumptions in the study- The side slope is taken as 1V:1.5H and for the sake of uniformity, the width of embankment at the top is taken as 29.70 for all types of pavement. Also for the study, logistics parameters of equipment, transportation and sources of materials and their lead distances are adopted as prevalent for the NH-8 project. Crushing and mixing plant for aggregate processing are assumed to be located at an average distance of 20 km from the site; the quarry located at 10 km away from the plant and borrow soil at an average lead of 10 km from the site. The subgrade CBR is 7% and the design traffic is 100 msa.

Table 44: GHG emissions from construction of various pavement options (using CHANGER software of IRF)

S. No	Construction type	Composition	Quantity of Construction Materials (Cum)	Cost (Rs crore)	Assessed GHG Emissions tonne-CO2 equivalent
1.	Conventional flexible pavement	BC = 50 mm DBM =145 mm WMM =250 mm GSB = 230 mm	34,008.95	5.51	1222.4
2.	Composite pavement having subgrade treated with cement	BC = 50 mm DBM = 60 mm Crushed Stone base = 150 mm Cement Treated subgrade = 500 mm	25,942.25	4.12	2183.68
3.	Composite pavement, subgrade treated with non-cement stabilizer	BC = 50 mm DBM = 60 mm Crushed Stone base = 150 mm Chemically Treated subgrade = 500 mm	25,942.25	4.12	940.23
4.	Conventional cement concrete pavement	PQC = 300 mm DLC = 150 mm GSB = 150 mm	31,722.25	5.57	3647.16

Source: (Dr P. K.Reddy Nanda and N Madhava, 2011)

of various options are designed as per relevant national/ international standards and specifications. Cost of construction is worked out as per the Delhi Schedule of Rates (DSR) and GHG emissions are assessed by using the World Bank software CHANGER[6]. Summary of all these four evaluated options in terms of consumption of materials, cost and GHG emissions is presented in Table 44. This study finds that the composite pavement having subgrade stabilized with zero-carbon based stabilizer emerges as the best option with regard to CO_2 emissions reduction potential along with lesser material consumption and construction cost. Such type of studies must be performed during Preliminary/ Detailed Design Stage to choose low-carbon pavement design options.

Use of improved mechanistic-empirical (ME) pavement design procedures. 'Internationally, especially in USA and European countries, highway agencies have started following ME pavement design procedures, such as the AASHTOW[7] Pavement Design Software' (AASHTOW, 2012). These ME pavement design procedures can produce more efficient pavement designs with acceptable performance by better accounting for specific traffic, climate, and other design conditions for the project. ME (mechanistic empirical) design permits better integration of materials and pavement design, as well as better consideration of construction quality requirements and hence the pavement is expected to have better performance in its life with optimized use

[6] CHANGER Software has been developed by International Road Federation (IRF) for the calculation and modelling of Greenhouse Gas Emissions (GHG) from road construction projects. The main objectives of the CHANGER are to achieve tangible, long term benefits for the global environment and to contribute proactively to the shaping of dynamic sustainable road development policies.

[7] American Association of State Highway and Transportation Officials

of materials and less maintenance, thus reducing CO_2 emissions through pavement life cycle (Steve Muench Dam, and Tom Van, 2014).

Estimation of carbon emissions should be made mandatory submission for every detailed project report that is submitted for approval to highway agencies. Additionally, review of specifications to allow the changes in appropriate designs with supporting technologies, preferring those which offer lower GHG emissions should be taken up.

4.2 Pre-construction stage

4.2.1 Site clearance (clearing and grubbing)

Site clearance includes clearing of vegetation and trees that come in the alignment of the highway. Vegetation, especially trees, store and sequester large amounts of carbon, providing an important service to the society: carbon dioxide uptake. The importance of trees in carbon sequestration has been recognized; in India, there are environmental obligations for contractors to re-plant the number of trees, which are cut for construction of roads. This helps in reducing the loss of carbon sequestration potential from road construction. Additionally, only the number of trees which are absolutely necessary should be cut/transplanted, if possible. To enhance the carbon sequestration potential, the Ministry of Road Transport and Highways has launched the National Green Highway Mission to increase the vegetation cover along the National Highways.

At the site clearance stage, more efficient machinery should be used to remove/relocate tress. Conventionally, crawler is widely used for site clearance purpose. According to MoRTH specifications, 'a crawler or pneumatic tyred dozer of adequate capacity may be used for site clearance purposes. The dozer having ripper attachments can be used for removal of tree stumps'. (MORTH, 2013). These equipment largely use diesel, and in future have the potential of being made more fuel efficient or run on alternate/cleaner fuels. Equipment and their use can also be made more efficient by training the operators.

After reviewing several journals and carrying out various consultations with stakeholders it was found that currently no such equipment is being used on the ground. Prototypes of these equipment using cleaner fuels are being developed/tested. However, it is recommended that the equipment and machinery used during clearing and grubbing should also be efficient and can be run on cleaner energy. Based on the discussions with the stakeholders, no such equipment or cleaner energy is currently being used in India.

4.2.3 Investigation of effective material transport and storage

During pre-construction stage i.e. before the start of procurement of construction materials, following carbon reduction intervention can be considered by the contractor and road agencies:

- Investigation of the condition of access road and leads from which construction materials are transported - If the condition of the access road is bad then the feasibility of other alternate route/s can be studied. Better access roads can help reduce fuel consumption and CO_2 emissions being generated from transportation of construction materials.
    - The government/private road agencies should ensure that the contractor has done proper investigation with regard lead of construction materials and condition of access road.
- Selection of location of storage of construction materials - The location of the storage of materials at site should be such that materials have the least distance from the road section where they have to be used; it can help in efficient transportation of materials within/on the site.
- Road contractors also need to consider the option of using latest technologies like GPS and ITS for better management of the fleet carrying construction materials, as it can help in reducing CO_2 emissions from transportation of construction materials.

4.3 Construction stage

4.3.4 Roadway lighting technology to be installed at construction site

During operation of highways, electricity is used in roadway infrastructure to power and operate street lights, traffic signals and changeable message signs. Electricity use results in indirect CO_2 emissions at power plants, which typically burn fossil fuels. There are three primary ways of reducing CO_2 emissions from lighting, all of which reduce the amount of electricity drawn from the grid. These could be considered during construction of highways during instalment of street lights and message signs.

- **Use more efficient lighting technologies, providing the same amount of light with less energy**

The main aim is to reduce the energy consumption, which can be done by practices like, use of low pressure sodium (LPS) street lights instead of high pressure sodium (HPS) street lights. Another practice is the use of LED traffic signals and message boards in place of incandescent ones. Most of the highways in India already have LED traffic signals. LEDs can also be used for traffic signals and changeable message signs.

- **Reduce the amount of lighting (in hours or intensity of light)**

It is a simple fact that if the amount of electricity used is reduced, the carbon emissions automatically comes down. This can be done by *turning off lights at certain times of day, reducing the brightness of lights, or in some cases eliminating lighting altogether* (John Bullough and Mark Rea, 2009).

The number of hours for which the traffic signals are used can also be reduced in order to reduce the energy consumption. This practice is prevalent in India, but mainly in some urban areas. Internally illuminated pavement markers and motion sensors to turn on lighting only when needed, can also be used.

- Use of renewable sources for highway lighting/ signals/message signs

More use of renewable sources of energy can reduce the carbon emissions. Decentralizing renewable energy sources can be explored and used to reduce the amount of electricity which is directly drawn from the grid. This could result in significant carbon savings. Lately, solar lighting systems are becoming popular for street lighting along roads and highways. A typical solar street lighting (SSL) system requires a photo-voltaic (PV) module with a capacity of 74-Wp, a 12 Volt flooded lead-acid battery, and a CFL of 11-W. This system is designed to operate from dusk to dawn, approximately 12 hours. The CFL automatically lights up when the surroundings become dark (IJEIT, 2013).

It has been estimated that 1,000 solar lamps can save upto 7485.82 (Md. Walid Islam et al., 2012) tonnes of CO_2 over a period of 20 years as compared to high pressure sodium vapor lamps. For instance, Nagpur city is saving 6.34 tonnes of carbon per year by replacing 142 sodium lamp streets light with the solar powered LED lights (International Renewable Energy Agency, 2007). Also, solar street lights are also being used in rural areas of Sundarban (West Bengal), Tamil Nadu and Andhra Pradesh (Dalmia Bharat Foundataion, 2009). With regard to National Highway sector, solar street light have been deployed on the Karur-Madurai section of NH-7 from km 305 to 426, Tamil Nadu[8].

4.4 Highway maintenance and operation stage

4.4.1 Highway maintenance

'A rough road slows down traffic and reduces efficiency, increasing fuel use and CO_2 emissions by 5-10 percent or more' (Asian Development Bank, 2010). Therefore, it is critical to save carbon emissions on account of bad quality of roads. According to (ADB, 2010a), emissions (CO_2 tons/km/year) increased by 1.6% when the road roughness increased from 2 m/km to 4 m/km; by 3.3 percent when the road roughness increased to 6 m/km; and by 5.8% when it increased to 9 m/km. 'This implies that if road roughness is limited to 3 m/km or lower with annual and periodic maintenance, the intensity of carbon emissions could be controlled.' (ADB, 2010a).

Effective preventive maintenance techniques/road surface treatments can be used to increase the life and quality of pavement so that less construction materials are required for maintenance and roughness of road can be maintained so that there are less emission from vehicles plying on the roads.

Road surface treatments are methods or materials for esxtending the lifetime of raod pavements, delaying the need for major maintenance or rehabilitation. There

[8] http://www.nhai.org/doc/ca/DINDIGUL%20BYPASS%20TO%20SAMYANALLORE%20ON%20NH%207%20IN%20THE%20STATE%20OF%20TAMIL%20NADU%20VOL%20-%20V.pdf; last accessed on

are various surface treatments practiced around the world and in India also like surface dressing, slurry seal, fog seal, microsurfacing and chip seal. No prominent research or studies have been undertaken in India to understand the carbon emissions reduction potential of using surface treatments as maintenance measures, which helps in increasing life and quality of pavement.

An international study was undertaken in UK (Alan Spray et al., 2014) in which carbon footprint of road surface treatments has been estimated. In this study, carbon emissions of surface treatment like slurry seal, surface dressing, velocity patching and mechanical retexturing etc. have been estimated. The estimated carbon emissions are shown in Table 45.

Table 45: CO_2 emissions from maintenance treatments

S. No.	Treatment	Kg CO_2 e/m²
1	Mechanical retexturing	0.51
2	Surface dressing	1.00
3	Slurry seal	2.87
4	Infra-red patching	5.52
5	Velocity patching	13.98

Source: (Alan Spray et al., 2014)

Box 9 shows the details of various maintenance technologies

BOX 9- DETAILS OF VARIOUS MAINTENANCE TECHNOLOGIES

The calculation of CO2 emission is done from cradle to laid which includes raw material extraction, material processing, material transportation, plant mobilization and plant operation.

Mechanical Retexturing

Pavement retexturing re-works an existing surface to improve its frictional characteristics and, therefore, skid resistance. There are three main methods for retexturing pavements, listed below, the first two being mechanical. They all work by restoring micro-texture to varying degrees, with some also improving macro-texture:

- Impact methods, such as bush hammering and shot blasting, where the surface is pounded by hard tipped tools or particles;
- Cutting and flailing, such as diamond grinding and grooving, combining a cutting action and impact on the cutting heads
- Fluid action, such as high or ultra-high pressure water jetting.

Surface Dressing*

Surface Dressing is a common and cost effective surface treatment used

- To provide a dust free wearing surface over a granular base,
- To provide surface impermeability against rainwater percolation into the pavement
- To arrest disintegration of the road surface
- To provide a non-skid riding surface
- To serve as a renewal coat for periodic maintenance of bituminous surfaces.

The Surface Dressing work consists of application (by spraying using a suitable equipment) of appropriate grade of bitumen/emulsion on a previously prepared base followed by application of a coat of cover material of appropriate size and grading and well rolled. Surface Dressing does not enhance the structural strength nor does it restore the riding quality of a surface having large surface irregularities. This technique has been extensively used in Gujarat

Slurry seal#

Slurry sear is a mixture of fine aggregates, mineral filler and emulsified bitumen with water added to achieve slurry consistency. The ingredients are mixed and spread evenly on to the bituminous surface to fill cracks, repair raveled pavements, smooth surfaces rectify loss of aggregates, rejuvenate oxidized and open textured old bituminous surfaces and provide a skid resistant surface

Infra-red patching method is in its inception stage in India and is in the list of new materials/Techniques/ Equipment accredited by Indian Road Congress (IRC) as 'Nu-Phalt Infra-Red Pothole Recycling Repairing System'.

This process, Nu-phalt in-situ Tarmac Recycling System, needs just two persons with a van and 22 minutes to repair a pothole. The process is simple. The pothole is first manually made dust-free and an infrared tarmac heater device is lowered from the van and placed on the pothole. The affected area is heated to about 200 degrees Celsius by a heater powered by gas and electrical feeders fitted in the van. After about 20 minutes, the heater is wheeled aside and the heated road material from the pothole is evenly spread in the cavity. An anionic binder is added to give more strength to the mixture. Finally, a vibrator device is rolled over the affected area to level it with the road surface. After the process is complete, traffic can immediately be allowed over the repaired surface. So unlike the existing procedure, this ensures minimum disruption to movement of traffic.

The company applying this technology in India is importing the technology from UK-based Nu-phalt in coordination with Texmaco Limited. The demonstration of this method is done from Municipal corporation of Delhi and this technology is tried out on pilot basis.

Velocity patching method in India has not been encountered so far. This method has been picked in this study from UK based technical paper and this technology is practiced in UK.

Velocity patching is used for defects of 75 mm or shallower, this technology uses a standalone truck that holds emulsion and aggregate and is equipped with a high pressure feed hose. Debris in the defect is blown away and a tack coat is applied and the asphalt is mixed and sprayed into the defect. The emulsion 'breaks' almost immediately and so traffic can resume straight away.

* *Sources : (IRC-110-2005), http://siteresources.worldbank.org/INTSARREGTOPTRANSPORT/3221770-1165232837016/21149972/12- Final-SurfaceDressing-Rawal-Gujarat.pdf; last accessed on*

\# *Source: IRC-82-1982*

4.4.2 Highway operations: Carbon emission reduction from vehicles plying oh highways

On-road vehicles are used for two primary purposes - passenger and freight transport. Total CO_2 emissions generated on account of operations of passenger and freight vehicles on highways is a function of the vehicle km travelled, fuel technology and fuel economy of fleet plying on highways. Strategies to reduce carbon emissions from highways operations therefore, need to target each of these areas, that is:

Target reduction in vehicle km on highways

Target use of cleaner fuels for highway operations

Target fuel economy improvements

Vehicle km (VKM), that is, the total vehicle activity that happens in highways is a function of vehicles (passengers and goods) on highway and daily km run. Reduction in vehicle km, therefore, requires reduction in number of on road vehicles and/or km run. Reduction in vehicle km on highways seems difficult, given the current trends in growth of vehicles. The only way to achieve it is by shifting to high occupancy passenger transport (rail or public transport) and high capacity freight transport (train transport and high capacity trucks).

Proper maintenance of vehicles and training drivers to operate vehicles more efficiently can also contribute to fuel efficiency. According to Cummins engines, '*The most efficient drivers get about 30 percent better fuel economy than the least efficient drivers*'. Installing fuel efficient tires and maintaining tires properly inflated also saves about 7% fuel.

Government agencies for example in USA set up training camps where the commercial drivers are trained to operate vehicles efficiently by accelerating and decelerating more smoothly in order to achieve better fuel economy and by maintaining vehicle regularly. Box 10 gives examples of some such activities/training programs conducted in USA.

BOX: 10:- EXAMPLES OF DRIVER TRAINING PROGRAMS IN USA TARGETING FUEL EFFICIENCY IMPROVEMENTS

- TxDOT educates its employees on eco-driving and energy saving maintenance practices including keeping engines properly tuned, checking and replacing air filters, keeping tires properly inflated, using the motor oil recommended by the manufacturer of the vehicle, driving at moderate speeds, accelerating and decelerating smoothly, and planning trips to minimize unnecessary mileage.
- Nevada DOT conducted a pilot project in 2010 on monitoring and improvement of driver behaviour. The agency contracted with SmartDrive Systems to install monitoring equipment on cars, pickup trucks, plough trucks, and other medium duty vehicles. The equipment records driver behaviour and uploads data to a central system. Reports on individual drivers are then provided to the DOT, so that remedial training of individual drivers can be conducted. SmartDrive has plans to develop a module that specifically analyses the fuel savings potential of improved driving habits.

Source: (Texas depatment of transportation, 2008-2009) , (Frank Gallivan et al., 2010)

4.4.3 Congestion/traffic management and speed control during highway operations

Speeds have a significant impact on fuel combustion. The '*ADB Evaluation Study – Reducing Carbon Emissions from Transport projects*' suggests that strategies like congestion management, speed management, and smoothing traffic flow, have proved to reduce emissions by 20%. The effects are expected to be larger for heavy duty trucks, which usually have lower power-weight ratio. Various studies suggest strategies like increasing/decreasing vehicle speeds to 50 kmph and reducing start stop traffic by smoothing traffic flow. The effect of these strategies should be studied in depth so as to achieve optimum speed that gives highest fuel efficiency. Box 10 discusses a few strategies for congestion /traffic management and speed control in highway operations.

4.5.4 Efficient toll collection management

Automated toll collection systems on highways are efficient way of toll collection as they reduce waiting time and the queues at the toll gates due to faster

BOX 11: STRATEGIES FOR CONGESTION / TRAFFIC MANAGEMENT AND SPEED CONTROL IN HIGHWAY OPERATIONS

(K.Boriboonsomsin and M.Barth , 2009) study suggests that speed management measures can help in CO_2 reduction. These are discussed below:

Congestion mitigation strategies: The main aim is to increase the speeds of the traffic to 50 kmph. This can be achieved through *ramp metering; enhanced traffic incident and operations managemen*t. Congestion pricing can also be used in urban highways. As in the case of buses, mitigation strategies like, designing bus bays to speed up the bus traffic, designing the bus stations for faster boarding and alighting, prioritizing busses at intersections and replacing slower and older buses with the new and larger ones, can be used.

Speed management techniques: The main aim of these techniques is to reduce the speed of the vehicles plying on road. This can be accomplished *by enforcement by police, radar, or cameras*.
In addition to enforcement measures, some voluntary measures could also be opted, *such as commercial vehicle operator training for eco-driving and fleet operator driver behavior monitoring systems*. Some of the new emerging technologies like active accelerator pedal and intelligent speed adaptation also help to monitor and reduce the speed of the traffic.

Traffic flow smoothing techniques: The main aim is to smoothen the traffic flow by reducing *stop-and-go traffic, suppressing shock waves, and reducing the number and severity of accelerations and decelerations*. This can be achieved by having variable speed limits and by using intelligent speed adaptation. Smoothing the traffic flow has been found to help reduce about 12%of CO_2 emissions. *The greatest CO_2 reduction benefits from smoother traffic flow are to be obtained in the 8 kmph–55 kmph speed range, where reductions in CO_2 per vehicle km travelled of one-third or more are possible*.

Source: (K.Boriboonsomsin and M.Barth , 2009) collection of tolls. The conventional method (manual collection) of toll collection contributes to more CO_2 emissions due to stop-and-start traffic and queue delays. Toll collection can be automated by using toll transponders, automated license recognition, or satellite-based global positioning systems[9]. The FASTag being promoted by MoRTH for hassle free movement on highways should help in this direction. Moreover, LED signals, LED message boards, bio-toilets and efficient energy consumption at toll collection booths can also be advocated for reducing emissions from toll operations.

4.4.5 Disposal of material after reaching end of life

For the flexible pavement, the materials reaching end of life such as bituminous layers and granular layers, can be reused in rehabilitation or new construction of pavement. Bituminous materials can either be recycled as RAP (recycled asphalt pavement) and used in new bituminous layer or it can be also used as granular layers if not found suitable for RAP. The granular layers can be reused either as improved subgrade materials or as embankment fill. All such reuse of pavement materials can reduce the demand of virgin aggregate and good quality soil or borrow area soil, which ultimately can reduce the CO_2 emissions from extraction and transportation of construction materials.

The concrete pavement starts to sequester the ambient CO_2. But this happens only in the top (exposed) part of the pavement. After the serving period of the concrete pavement, the removed pavement should be crushed and stock pilled for one year before reusing it, so that it can sequester the CO_2. The study of (Nicholas Santero et al., 2010), shows that '*crushing and stockpiling the concrete for 1 year, sequester 28 percent of the initial CO_2 released from carbonation, or 155 grams of CO_2 per kilogram of cement in the mix*'.

4.5 Alternate materials (new/reused/ recycled/) and green technology

4.5.1 Waste materials

Waste materials from construction have started getting used as a substitute to the conventional construction materials. Using the waste materials can avoid the need to consume new raw materials for road construction of roads and can thereby reduce CO_2 emissions form road construction.

Substantial amount of research work has been done to quantify the economic and environmental gains of using waste materials like blast furnace slag, fly ash, silica fume (from power plants), recycled aggregates (from demolition sites), plastic waste (domestic waste), marble dust and rubber waste (commercial waste). These are some of the most widely used waste materials in road construction.

Fly Ash

Fly ash is a by-product of thermal power stations and industrial plants using pulverized coal as a fuel for the boilers. It is a fine cementitious powder, consisting primarily of silica, alumina and iron. When mixed with lime and water, the fly ash forms a compound with properties very similar to that of Portland cement (Thomas, 2009). The use of fly ash as a pozzolana and fine aggregates is well established in construction sector.

The uses of fly ash in road construction are discussed below:

Construction of embankments– It can save excavation and transportation of good soil to construct embankment, thus helping in reducing CO_2 emissions.

Stabilizing subgrade – Fly ash is mixed with local soil along with lime; this mixture increases the strength of soil. It can also be used in stabilizing and constructing sub-base or base.

Using concrete with fly ash– Mixing concrete with fly ash (10%–20%by weight) is a cost effective method of improving performance of rigid pavement, which also helps in reducing the quantity of cement consumed.

Mineral filler - Fly ash can be used to fill the voids and make bitumen mix more compact to increase the strength of the mix. This can act as replacement for many binders such as Portland cement or hydrated lime. *For use in bituminous pavement, the fly ash must meet mineral filler specifications outlined in MoRTH specifications* (M. N Aktar and J Alam , 2011).

9 http://www.indiantollways.com/category/delhi-gurgaon/; last accessed on

Kerb casting– Fly ash can also be used in kerb casting by replacing 50% of cement with fly ash. *M25*[10] *Grade slip forming Kerb was casted by Gujarat State Highway projects*. (M. N Aktar and J Alam , 2011)

Up to 35% of fly ash can be substituted for cement as blending material. Addition of fly ash improves the quality & durability characteristics of resulting concrete. Fly ash up to 20% by weight of Cement may be used in 53 Grade Cement (Jigisha, 2011).

'Guidelines for Use of Fly Ash in Road Embankment' are given in IRC: SP-58 2001. Notification No. S.O. 979(E) dated 27th August, 2003 published in the Gazette of India. The Guidelines state that '*no agency, person or organization shall, within a radius of 100 km of a thermal power plant undertake construction or approve design for construction of roads or flyover embankments in contravention of the guidelines/ specifications issued by the India Road Congress (IRC) as contained in IRC specification No. SP: 58 of 2001'.*

Concrete recycled aggregate/building waste

The aggregates obtained from construction and demolition waste (CDW) can be re-used in road construction for flexible/rigid pavement construction, as kerb stores, paves blocks, etc. This can reduce use of virgin aggregates in road construction, which in turn can help in reducing extraction of natural aggregate and less transportation requirement, thereby reducing CO_2 emissions from use of vision aggregates in road construction.

Several studies have indicated that *building debris can be effectively used as road material.* Several other studies have suggested potential use of CDW in embankment and sub-grade construction, sub-base construction, stabilized base course construction and rigid pavement construction (Tushar R Sonawane and Prof. Dr. Sunil S. Pimplikar, 2012). Construction and demolition waste was used as road base for M7 Clem Jones tunnel Queensland and 20% reduction was seen in material cost on account of savings in transportation (Prof. Newman et al., 2012) ,also it was seen that 1,000 tonnes of CO_2 (Prof. Newman et al., 2012) was saved for the construction of 4.8 km '*It has been analysed that the performance of blended mixture of 25% of recycled concrete aggregates with 75% of natural aggregate in the base course application has the same resilient response as the dense graded aggregates of base course made of natural aggregates. The strength and compactability of recycled CDW aggregates is similar to the conventional WBM or WMM*' (Rajiv Goel and Ashutosh Trivedi, 2015).

Ground granulated blast furnace slag (GGBFS)

Blast furnace slag is a by-product of steel plants. It is generated during the extraction of iron from iron ores. *Granular Blast Furnace Slag (GBFS) consists of non-ferrous components contained in the iron ore together with limestone as an auxiliary material and ash from coke. Depending on the cooling method used, it is classified either as air-cooled slag or granulated slag* (B G Buddhdev and Dr H.R Varia, 2014).

GBFS can be used as a highway construction material in embankment and subgrade to increase the stability of parent soil. California Bearing Ratio (CBR) tests should be conducted to check the effect of adding slag on the strength of the soil. Different contents of slag can be added to the soil to check performance of the soil with slag (GBFS), and if found suitable, can be used in embankment and subgrade construction.

Various studies have been conducted for showing the utilization of GBFS as highway construction material (mostly for partial replacement of soil and concrete), but the practical application of GBFS in road construction is not very widespread. Engineers and consultants should consider GBFS wherever available as use of GBFS help in reducing the CO_2 emissions from road construction.

Copper slag

Copper slag is produced in India at a rate of about 5000 tons/day and its total accumulation till date is more than 7 million tons. At present, copper slag is being used for shot blasting, as additive for cement manufacturing, for land filling, etc.[11] *but these applications utilize only about 10% to 20% of the total waste material produced* (V.G. Havanagi et al., 2012)*and the remaining quantity is dumped as a waste material. Copper slag has the potential for use in road base construction, railroad ballast and as engineered fill.* (V.G. Havanagi et al., 2012) studied the feasibility of copper slag in the

[10] What is M25: M refers to Mix and 25 refers the characteristic compressive strength of concrete cube of 150 mm X150 mm, X150 mm tested at the end of 28 days should be minimum 25 N/Sq.mm

[11] https://www.civil.iitb.ac.in/tpmdc/PAPERS/205.pdf; last accessed on

construction of road with or without stabilization and found that copper slag has high amount of Fe_2O_3, SiO_2, Cao and other chemicals (Braja M. Das et al., 1982), which makes it amenable for chemical stabilization. The use of copper slag in embankment construction is generally done by mixing 25% to 50% of copper slag with a mixture of any local soil and pond ash. It is found that mix of copper slag with locals soil mostly satisfy MoRTH (2001) criteria for use in embankment construction. It has been found that addition of copper slag increases the angle of internal friction, which varies in the range of 32^0 to 35^0. The observed high values indicate the suitability of these mixes for the construction of high embankments. Moreover, the CBR of the soil and copper slag also increases to about 20% to 30% with permeability in the range of $0.4x10^{-}4$ to $3x10^{-6}$ m/sec. All these engineering values show that copper slag (25%–50%) mixed with local soil can be very well used as embankment material, thus saving on the excavation and transport of good soil, thereby reducing CO_2 emissions in road construction.

There are certain case studies where use of copper slag in road construction has conducted which are listed below (V.G. Havanagi *et al.*, 2012):

The National Highway 45-B is being widened to four lane from the existing two lane. The copper slag industry is just by the road side and the slag is recommended to be used in embankment and in different layer of road pavement.

Construction of experimental test track of length 1 km road is being carried out on Madurai-Tuticorin expressway, NH-45, Tamil Nadu. Four sections will be carried out with different specifications using mixes of copper slag/pond ash/soil and a fifth test section with conventional road materials monitored for a period of 2 years by collecting.

There is a need of more awareness for the use of copper slag in road construction so that the engineers, consultants and contractors can use copper slag thereby reducing CO_2 emission from road construction.

Foundry sand

Foundry industries are widely spread in India. The basic operations of these industries are metal casting. Foundry industries generate waste foundry sand which is used for landfills or is disposed near water sources creating environmental hazards. Foundry sand can be used in road construction. Studies show that waste foundry sand can be used as the fine material in road base. Engineering properties that characterize foundry sand as a sub base material are plasticity, shear strength, compaction, drainage and durability. Waste foundry is non-plastic sand, which is comparable to conventional sand. Its shear strength is superior to silts, clays or dirty sands, indicating that foundry sand has also the potential for use as an embankment material as it has more permeability than materials conventionally used for embankment construction. There is a need to promote use of foundry sand in road construction, which at present is very low. It can help address environmental concerns related to disposal of foundry waste and can also help reduce CO_2 emissions from road construction.

Marble dust

Solid waste and stone slurry are some of the major by-products of the marble industry. Solid wastes are the rejects from the mine sites or at the processing units and stone slurry is a semi liquid substance resulting from the sawing and the polishing processes. '*Stone slurry generated during processing corresponds to around 20 percent of the final product from stone industry* (Anwar, 2014). Due to environmental and health hazards, disposal of slurry is a concern. *The marble powder although non plastic contains an appreciable colloidal fraction, which significantly reduces the permeability and allows the deformation without cracking which is desirable for any non- permeable structure*' (Gurumoorthy, 2014). In road construction, it can be used as a substitute to fine aggregate due to its good binding property. By using marble dust, there can be less demand for fine aggregates, which can reduce CO_2 emissions from road construction.

4.5.2 Alternate Materials[12]

Marginal aggregate

'*Marginal materials are any material not wholly in accordance with the specification in use in a country or region for normal road materials but can be used successfully either in special conditions, or in recent progress in road techniques or after subjecting to particular treatment.*'[13]

[12] (Javed, 1992), (M.S.Verma, 2014), (Shih-Hsien Yang , 2006)

[13] http://pmgsy.nic.in/marginal.pdf; last accessed on

The marginal materials generally include Foliated metamorphic rocks (that do not meet the requirements of a crushed stone base), shales (weakly cemented, poorly consolidated, partially weathered rocks), Natural Gravels, Moorum, Laterite, Brickbats, Construction and Demolished waste. These marginal materials can be successfully used for highway construction where traffic is comparatively low, environment is understood and accounted for in design, quality control is adequate and timely maintenance is possible. The use of marginal aggregates reduces the demand of high quality natural aggregates along with eliminating the transport of natural aggregates from larger leads, which ultimately saves energy and reduces CO_2 emissions from aggregate extraction and transportation.

There are not many guidelines and specifications for the use of marginal aggregates in India, especially for national and state highways. There is only one code - IRC SP: 72, which has some guidelines for the use of locally available materials. The rural roads manual (IRC: SP 20-2002) has laid down specifications for the use of marginal aggregates in rural roads. Some studies like (Ajay Swarup et all, 2015) and (Dr. Suresh Kumar and Er. Nazish Akhtar, 2016) have also encouraged the use of marginal aggregates, including those on highways with high density traffic. Present guidelines for the use of marginal materials suggest specifications, which are somewhat stringent and on the higher side. This makes the use of marginal materials in construction of roads difficult. Significant amount of research is needed for the use of marginal aggregates leading to preparation of revised guidelines and specifications.

Vetiver grass

Vetiver grass is used for protection of soil slopes from erosion. It is a low cost and environmental friendly solution and has been recognized as an efficient slope stabilization method in many countries around the world. It is extensively used in some parts of Asia, Africa and the US. As the Government of India has embarked upon developing green roads, vetiver grass is a good option to use in slope protection work in road construction, as it reduces the use of boulders and stones for pitching, concrete and stone rip-rap, stone filled gabion baskets, and masonry walls used as slope protection work, thereby reducing CO_2 emissions from extraction and transportation of aggregate.

These plants also sequester CO_2, which further helps in achieving the goal of green road construction. '*Vetiver grass, a C4 plant, can absorb about 1.5 Kg carbons per plant per year*' (Paul Truong *et al.*, 2015). Earlier, promoted to help conserve soil and water for agriculture by the World Bank in the 1980's and 1990's (Greenfield 1989 and National Research Council 1993), Vetiver grass has evolved in the late 1990's as an important soil bioengineering tool.

The Vetiver grass green technology is in its inception stage in India and is being used in a limited number of projects. It was used at Doria bridge approach in the river island Majuli, Assam. There is no rock/ boulder available in the entire island. Transportation of the boulder from elsewhere is exorbitantly costly. Planting was carried out in April 2010.The length of the embankment is about 200m on either side. Vetiver grass was planted at a spacing of 150 mm and it performed satisfactorily even during heavy rains.

Vetiver grass provides an alternative tool for erosion control on slopes and can be used in combination with traditional engineering structures. It can help in controlling the erosion of road batters, bridge approaches, high embankments, road without cross drainage, mountain roads etc. in an economical and environment friendly manner.

Annexure 5: List of People Contacted for Collecting Primary Data

Table 46: List of people contacted to collected primary data from sites

Sr. No.	Contact Person	Designation	Organization	Location	State	Contact details
1	Mr Pasang Negi	EE	PWD	Rampur	Himachal Pradesh	9418027276
2	Mr U C Katara	RO	MoRTH	Dehradun	Uttarakhand	9968313197
3	Mr Navneet Pandey	EE	MoRTH	Dehradun	Uttarakhand	9997976809
4	Mr Pravin	EE	MoRTH	Dehradun	Uttarakhand	8191011910
5	Mr Prashant	EE, PWD	MoRTH	Dehradun	Uttarakhand	9997229966
6	Mr Sandeep	PWD	MoRTH	Dehradun	Uttarakhand	9557026038
7	Mr S K Mishra	PD, PIU	NHAI	Jodhpur	Rajasthan	8290523230
8	Mr Satyendra Singh	EE, NH	NHAI	Jaipur	Rajasthan	9414081373
9	Mr Kasar	-	NHAI	Jaipur	Rajasthan	9587629399
10	Mr Sivsankara	PD, PIU	NHAI	Lucknow	Uttar Pradesh	8419086666
11	Mr Naveen Mishra	PD, PIU	NHAI	Kanpur	Uttar Pradesh	7860563333
12	Mr Mahesh Kumar	Project Manager	OBIL	Orai	Uttar Pradesh	7408423550
13	Mr Umesh Mishra	Project Manager	Oriental Construction	Etawah	Uttar Pradesh	7408433301
14	Mr Bishnu Murthi	RO	NHAI	Patna	Bihar	9473373844
15	Lt. Col. Ajay Thakur	GM, PIU	NHAI	Patna	Bihar	7542020504
16	Mr B K Jha	Project Manager	Patna-Bakhtyarpur Toll Management Company Limited	Patna	Bihar	9771497636
17	Mr Digvijay		Patna-Bakhtyarpur Toll Management Company Limited	Patna	Bihar	9771422346
18	Mr Behera	PD, PIU	NHAI	Vizag	Telangana	9437231723
19	Col. George Mathews	Project Manager	NHAI	Bhubaneshwar	Odisha	9938555775
20	Mr Sanjay Gangurde	CE, Mumbai-Pune Expressway	MSRDC	Pune	Maharashtra	9967918099
21	Ms Namrata Reddy	EE	MSRDC	Pune	Maharashtra	9860834755
22	Mr S Yadav	Site engineer	MSRDC	Pune	Maharashtra	8554916844
23	Mr Subodh Kumar	AEE, Planning	MoRTH	New Delhi	Delhi	9470333323
24	Mr S Manivasagam	Planning & Information System	NHAI	New Delhi	Delhi	9818824824

Annexure 6: Terrain-wise Length of National Highways in Key States

Table 47: Terrain-wise length of National Highways in key states

States	Mountainous & steep	Plain	Rolling	Grand total
Andhra Pradesh	-	2,369	-	2,369
Assam	119	472	45	637
Bihar	-	1,995	-	1,995
Gujarat	516	1,094	-	1,610
Haryana	-	1,153	-	1,153
Himachal Pradesh	188	9	39	236
Jammu & Kashmir	206	52	120	378
Jharkhand	-	673	121	794
Karnataka	41	2,106	185	2,333
Madhya Pradesh	83	1,807	707	2,597
Maharashtra	71	3,455	373	3,900
Meghalaya	57	-	155	213
New Delhi	-	32	-	32
Odisha	-	1,960	-	1,960
Puducherry	-	4	-	4
Punjab	4	519	6	529
Rajasthan	-	4,148	-	4,148
Tamil Nadu	-	3,428	-	3,428
Uttar Pradesh	-	4,121	-	4,121
Uttarakhand	-	459	-	459
West Bengal	-	1,120	-	1,120
Grand total	1,287	30,977	1,753	34,016

Note: Data is available for only those states that have submitted the information to the MoRTH in a prescribed format

Source: Ministry of Road Transport and Highways

Annexure 7: Map Indicating a Terrain-Wise National Highway Network

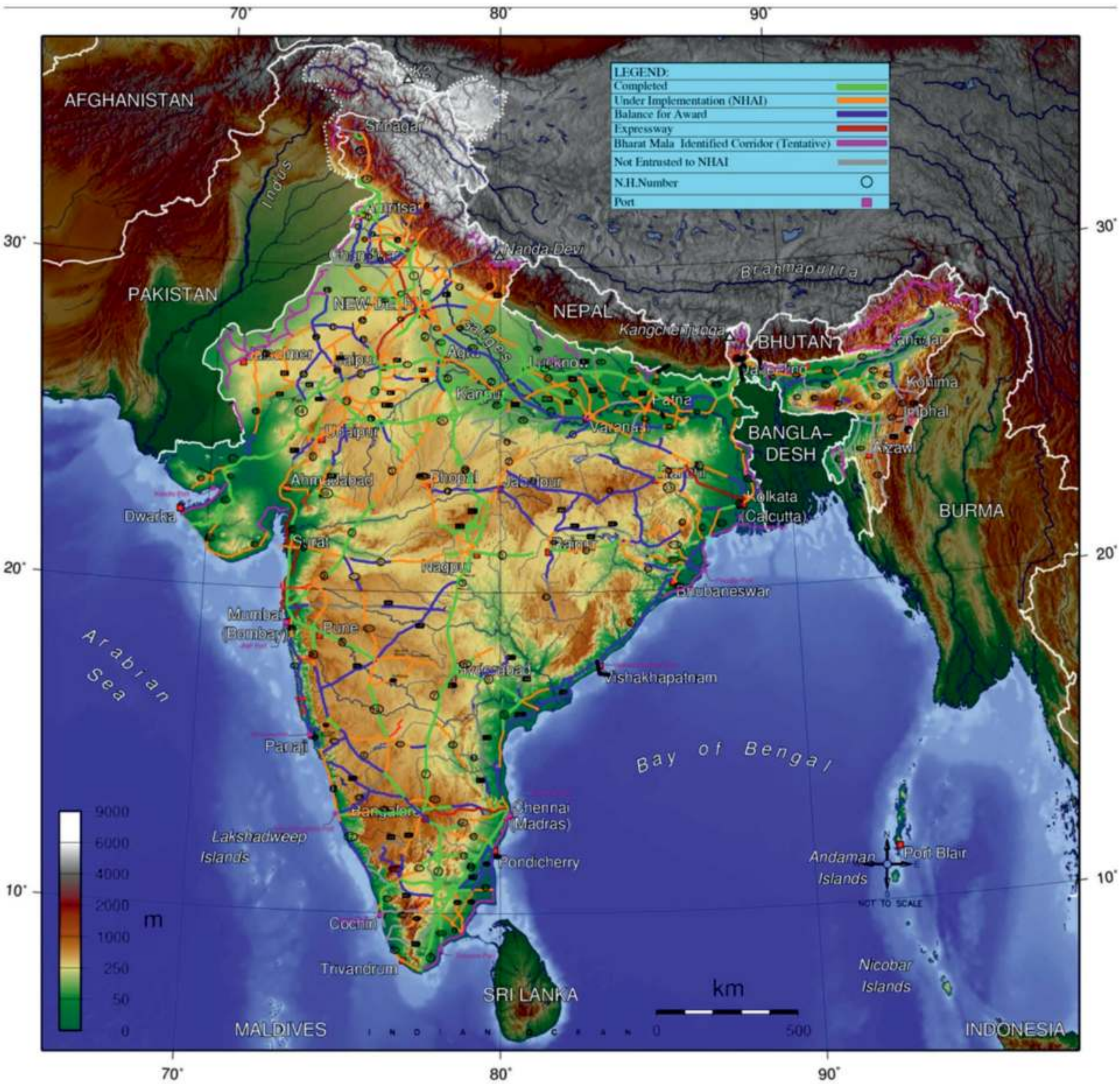


Figure 28: Overlapped map of Indian National Highway network with the Indian terrain map

Annexure 8: International Best Practices

Table 48: Summary of International best practices in mainstreaming carbon footprint in policy

Country	Phase	Department	Policy in Brief	Remarks
Australia	Operations	Department of Environment and Energy	Quarterly Update of Australia's National Greenhouse Gas inventory: the report presents statistics of carbon emissions for various sectors including transportation sector. It depicts the different kinds of fuel consumed by the transport sector[14]. [June 2016]	India still doesn't have a system wherein it calculates the GHG emissions on a quarterly basis for all the sectors.
	Operations	Department of Transport and Regional Services	Sensitising the consumers about fuel efficiency of cars through an informative website that provides all the emissions related data for all the vehicle models since 2004[15].	The sensitization process also involves applying a sticker on the car's wind-shield that displays the mileage and carbon emissions.
	Operations	Department of Transport and Regional Services	Fuel Tax Credits for Heavy Diesel Vehicles: 4 criteria required -1) Vehicles Manufactured on or after 1 January 1996. 2) Vehicles registered in an audit maintenance program that is accredited by Transport Secretary. 3) Vehicles that meet rule 147A of the Australian Standard Rules 1999 (the 'DT80' test). 4) Vehicles which comply with the maintenance schedule endorsed by the Transport Secretary[16]. [2006]	
	All	Australian Government	Emission Reduction Fund: The Government of Australia funds projects which aim at reduction of emission across all economic sectors[17]. [2016]	

[14] www.environment.gov.au/system/files/resources/48275b92-3f4b-44d0-aa4e-50ece408df86/files/nggi-quarterly-update-jun-2016.pdf; last accessed on

[15] www.greenvehicleguide.gov.au

[16] www.infrastructure.gov.au/roads/environment/fuel_tax_credit/files/Guidelines-for-Environmental-Criteria-Fuel-Tax-Credit-for-Heavy-Diesel-Vehicles.pdf; last accessed on

[17] www.infrastructure.gov.au/roads/environment/forum/files/Vehicle_Emissions_Discussion_Paper.pdf; last accessed on

United States	Construction/ Maintenance	Federal Highway Association (FHWA)	Recycle Material Policy: The policy includes a course developed by the FHWA Recycling team and the National Centre for Asphalt Technology (NCAT) to sensitize the engineers about the need for recycling of construction materials and its economic and environmental benefits[18]. [2002]	Such type of sensitization will increase the people's knowledge about the various recycle materials available and how cost effective the utilization of these materials could be.
	All	FHWA	Pavement LCA Framework: a guide that is included in the planning phase by the FHWA to help develop a more sustainable highway[19]. [2016]	A singular framework of LCA for the National Highways is needed.
	Construction/ Maintenance	FHWA	Infrastructure Carbon Estimator: a tool that helps in the calculation of carbon emission from a particular construction and maintenance project[20]. [2014]	The tool helps in realising areas where improvements can be done to reduce the overall carbon emissions. It also helps in estimating the pros and cons of implementing a particular project through simulation.
	Operations	FHWA	National Electric Vehicle Charging and Hydrogen, Propane and Natural Gas Fuelling Corridor: The FHWA has identified 55 routes across 35 states for the designing of dedicated corridor[21]. [January 13 2017]	India has started the integration of CNG in the transport system, and can further encourage this by providing CNG dedicated corridor for the freights and commercial vehicles on highways.
	Construction/ Maintenance	FHWA	Under the FAST Act (Fixing America's Surface Transport) Sec. 1428 the FHWA has encourage the use of durable, resilient, and sustainable materials and practices[22]. [2015]	The law states the use of geo-synthetic materials which are economic and environmentally safe.

[18] https://www.fhwa.dot.gov/legsregs/directives/policy/recmatpolicy.htm; last accessed on
[19] https://www.fhwa.dot.gov/pavement/sustainability/hif16014.pdf; last accessed on
[20] https://www.fhwa.dot.gov/environment/sustainability/energy/tools/carbon_estimator/; last accessed on
[21] https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/resources/section_1413_report/fhwahep170.pdf; last accessed on
[22] https://www.gpo.gov/fdsys/pkg/PLAW-114publ94/pdf/PLAW-114publ94.pdf; last accessed on

European Union	Construction/ Maintenance	Sweden Road Administration (SNRA)	Sweden has employed a tax on the use of virgin materials consumed in the construction of highways (of about US$0.57 for each metric ton) (Vincent E. Schimmoller, 2000).	These efforts are in the direction of recycling of road construction materials for the efficient and cost effective utilization of resources.
		Danish Government	Denmark has strict laws for the use of virgin material in the construction of highways (about US$0.65 for every cubic meter used) (Vincent E. Schimmoller, 2000).	
		Dutch Government	The Dutch government has employed steep taxes on landfills and waste-disposal of materials (charging US$35 to US$352 per metric ton of waste) and has phased ban on landfill of 32 materials which includes construction and demolition waste – encouraging the use these materials for highway construction (Vincent E. Schimmoller, 2000).	
	Operations	UK Department for Transport	UK's Department for Transport has started a Safe and Fuel Efficient Driving program under which handbooks, training and guidance is provided for efficient and safe driving to Heavy Goods Vehicle drivers and Light Goods Vehicle drivers[23]. [2007]	In India there is a need for sensitization with respect to the best driving practices which will help freight vehicle travel efficiently and safely.

[23] http://postconflict.unep.ch/humanitarianaction/documents/02_08-04_06-04_02-22.pdf; last accessed on

Annexure 9: Site Photographs

Photo 1: Crusher unit for the upgradation of the Jodhpur–Pokhran NH-114

Photo 2: A section of the Jodhpur–Pokhran stretch before

Photo 3: Expansion work under the Jodhpur–Pokhran section of NH-114

Photo 4: Weighing of bituminous mix for the periodic maintenance of the Orai–Barah section of NH-25

Photo 5: Overlaying work on the Orai–Barah section of NH-25

Photo 6: Pavement quality concrete work under the Etawah-Chakeri project (Source: NHAI)

Annexure 10: Checklist for the Selection/Adoption of Interventions at the DPR Stage

Checklist for the selection/adoption of interventions at the DPR stage

S. No.	Intervention	Whether Considered for Use (Yes/No)	Reason for Accepting/Rejecting
	Use of green technologies such as		
1	Warm Mix Asphalt		
2	Cold Mix Asphalt		
3	Microsurfacing (maintenance phase)		
4	Soil Stabilisation		
5	Others		
	Use of waste materials such as		
6	Plastic Waste		
7	Fly Ash		
8	Construction and Demolition Waste or Recycled Aggregate		
9	Blast Furnace Slag		
10	Copper Slag		
11	Rubber Waste		
12	Foundry Sand		
13	Marble Dust		
14	Others		
	Use of alternate materials such as		
15	Reclaimed Asphalt Pavement		
16	Marginal Aggregates		
17	Geo-Synthetics		
18	Vetiver Grass		
19	Others		
	Interventions during the planning and design stages		
20	Designing the vertical grade with higher initial speed (with less than 6% vertical grade)		
21	Designing vertical curve with higher K-values		
22	Considering environmental impacts and CO_2 emissions while deciding route/alignment*		
23	Use of LiDAR Technology		
24	Pre-fabricated labour camps and offices		
25	Others		
	Interventions during the construction stage		
26	Use of slot dozing		
27	Use of railways for transportation of construction materials		
28	Use of efficient/green lighting technologies		
29	Others		

- Minimizing the lead for transportation of bulk materials, trees to be cut, relocation of trees, etc.

Annexure 11: Assumptions Considered for Estimating the Construction and Maintenance Phase CO_2 Emissions

Estimation of construction and maintenance related energy consumption and CO_2 emissions at project/stretch level

Estimation of number of trips made for transportation of material to/from construction/maintenance site: Average loading on trucks for different types of construction materials is assumed to remain constant across different trips for moving the material. The number of trips by trucks is a calculated field against this assumption of average loading and total material used.

Estimation of energy consumption for transportation of material to/from construction/maintenance site: The average fuel efficiency for different types of trucks used to move different materials is assumed to remain constant for all trips.

Estimation of idling related energy consumption during transportation of material to/from construction/maintenance site: Idling efficiency of trucks and tankers are assumed to remain constant throughout.

Estimation of maintenance related energy consumption and CO_2 emissions: The volume and type of materials used across different annual and periodic maintenance cycles for different stretches of highways are assumed to remain constant (i.e. same as the year for which maintenance data has been collected) during each cycle. It is also assumed that the maintenance activity is undertaken every year for annual maintenance and after a pre-determined number of years in the case of periodic maintenance.

Estimation of construction and maintenance related energy consumption and CO_2 emissions at national level

Total lane km calculation: Data was made available by MoRTH for total length of 2 lane, 4 lane and 6 lane and above National Highways. This was used to calculate the total lane km for the NH network with the assumption that the average lanes per km for the 6 and above lane highways are 6.5 lanes per km.

Total Highway Network (2015)		2 Lane	4 Lanes	=>6 Lanes	Total
Length	km	64,000	40,000	6,500	110,500
	Lane km	128,000	160,000	42,250	330,250
Average lanes per km of National Highways network		3.0			

National Highway network growth: It is assumed that the increase in the NH network will take place at the rate of 20 km of highways per day and the corresponding Lane km increase is calculated using the same Lanes per km figure from above.

Particulars	Length
Growth per day (km)	20.0
Growth per year (km)	7,300.0
Average Lane per km	3.0
Growth per year (Lane km)	17,022.2

Construction and maintenance emissions at national level, as explained in the main report, involve the following steps:

The total construction emissions per lane km is calculated by taking the total emission and dividing by the total lane km for which construction data is available.

Similarly, for maintenance the total maintenance emission per lane km is calculated by taking the total emission and dividing by the total lane km for which maintenance data is available.

This total lane km figure is then used to scale up the Construction and Maintenance emissions to the national level by multiplying the emission per lane km for construction and Maintenance.

The growth in emission from Construction and Maintenance is calculated on basis of per lane km emissions calculated above and multiplied with the total lane km for the year.

Annexure 12: Assumptions Considered for Estimating the Operations Phase CO_2 Emissions

NITI Aayog's India Energy Security Scenario (IESS) tool has veeb used to estimate CO_2 emissions from NH sector. Following are the set of assumptions used to determine the shares and volumes of traffic on the National Highways from the IESS transport demand estimates.

Estimating traffic on National Highways

Urban/non-urban segregation – method/ assumptions:

The IESS Tool estimates the total traffic on Indian roads based on the total number of registered vehicles in the country. To segregate the urban and non-urban traffic, the model takes as a starting point, the urban vehicle stock in India as per the vehicles registered across different Indian cities. The data for the number of registered vehicles in urban centres in India is maintained and collated by the Ministry of Road Transport and Highways and is published in the Ministry's report called the Road Transport Yearbook[24] The last year for which this data is available is 2014-15.

The IESS Tool determines the urban road traffic based on the total number of vehicles registered across Indian urban centres and assumes the remaining vehicle stock to be non-urban mobility.

The resulting shares of passenger traffic on different roads are as follows:

The resulting shares of freight traffic on different roads are as follows:

% of passenger traffic on type of sub-mode	2016-17
N. Highways (surf)	30%
N. Highways (non-surf)	-
State Highways (surf)	10%
State Highways (non-surf)	5%
PWD Roads (surf)	10%
PWD Roads (non-surf)	5%
Rural Roads (surf)	19%
Rural Roads (non-surf)	1%
Urban Roads (surf)	16%
Urban Roads (non-surf)	4%

% of freight traffic on type of sub-mode	2016-17
N. Highways (surf)	50%
N. Highways (non-surf)	-
State Highways (surf)	20%
State Highways (non-surf)	2%
PWD Roads (surf)	4%
PWD Roads (non-surf)	2%
Rural Roads (surf)	10%
Rural Roads (non-surf)	1%
Urban Roads (surf)	5%
Urban Roads (non-surf)	2%

Fuel technology assumptions for highway traffic (base year)

Following are the fuel technology assumptions used for the passenger and freight vehicle categories assumed to operate on highways under the IESS reference scenario.

Mode	Technology types (2016-17)					Technology types (2030-31)				
Passenger	P	D	CNG	LPG	E	P	D	CNG	LPG	E
Cars	70%	22%	3%	3%	3%	51%	31%	4%	4%	10%
Taxis	-	95%	3%	2%		-	82%	4%	1%	13%
2W	100%	-	-	-	-	85%	-	-	-	15%
3W	40%	37%	11%	9%		40%	27%	15%	8%	11%
Buses		99%	1%	-		-	95%	2%	1%	2%
Freight										
LCV	-	100%	-	-	-	-	100%	-	-	-
HCV	-	100%	-	-	-	-	100%	-	-	-

P: Petrol; D: Diesel; E: Electric

[24] http://morth.nic.in/index2.asp?slid=291&sublinkid=137&lang=1; last accessed on

Annexure 13: Terms of Reference for the Study 'Carbon Footprint in Highway Sector'

Terms of Reference for Consulting Project on reduction of "Carbon Footprint in Highway Sector"

Background

Transport of people and material is vital for a nation. It contributes to economic growth, improves resilience, and requires energy to move resources in a way that all citizens benefit from its progress. Transport, therefore, requires fuel, which is mostly carbon-based. At the same time, growing concerns around climate change are leading policy makers to identify sectors where anthropogenic emissions of Green House Gases (GHG) can be controlled effectively to avoid some of its projected catastrophic and some persistent effects. GHG emissions from transport represent one of the most significant sectoral emissions, and one of the few that are rising, even when technology and other choices are helping reduction or stabilizing of GHG emission rates.

In the climate action plan or the Intended Nationally Determined Contributions (INDC) submitted recently (October 2nd, 2015) to the United Nations, Government of India targets to reduce the emissions intensity of GDP by 33% to 35% from 2005 levels by 2030. India has adopted several ambitious measures for clean and renewable energy, energy efficiency in various sectors of industries, achieving lower emission intensity in the automobile and transport sector, non-fossil based electricity generation and building sector based on energy conservation. Thrust on Renewable Energy, Promotion of Clean Energy, Enhancing Energy Efficiency, Developing Climate resilient Urban Centers and Sustainable Green transportation Network are some of the measures for achieving this goal.

Various policies like National Policy on Biofuels, Green Highways Policy, Solar Powered toll plazas, Mass Rapid Transit System (MRTS) in urban areas, Dedicated Freight Corridors, Green India Mission, etc. are being implemented to achieve the goals committed in INDC. On the same lines, Ministry of Road Transport and Highways (MoRTH) intends to undertake this study that aims to reduce the carbon footprint of the highway sector within the overall context of India's commitments that have been included in the INDC.

At the same time, investments in the transport sector are among those most vulnerable to changes in climate variables. These are due to enhanced and expected changes in the frequency and intensity of extreme weather events. Specifically, these include increased sea level (coastal highways), increased landslides due to intense precipitation (hilly & mountainous highways), and flooding (across highways in the plains). Given India's extensive coastlines and mountainous topography, the highways infrastructure of Asia and the Pacific are particularly exposed to projected changes in climate. In order to attain a better understanding of the interventions required to address climate change impacts, MoRTH intends to undertake this study.

Scope of Work

The overarching objective of the assignment is to help MoRTH reduce carbon footprint and enhance climate resilience of the highway sector in the country through adopting and mainstreaming appropriate policies, strategies and enabling actions.

The scope of work of the study is divided into two parts:

- Part 1 of the study will focus on aspects pertaining to the carbon footprint of highways
- Part 2 of the study will focus on aspects pertaining to building climate resilience of highways

Part 1: Reducing the carbon footprint of highways

1. To carry out a review of literature in general, and in particular to highways in order to determine accepted approaches towards the carbon foot printing of highways in the construction, operation and maintenance phase[1]. To document the carbon estimates per km of highways in India, and extrapolate to determine the overall carbon footprint of the NH network. To compare these estimates with those of the country across all sectors as well as highway sector of other developing and developed countries.

2. To identify and list comprehensively carbon-reducing interventions, both engineering and non-engineering, that are relevant in the planning, design, construction, operation and maintenance phases of the highway projects[2]. To provide cost estimates of these interventions, and to indicate them as absolute numbers or as a percentage of total project cost.

3. To estimate the carbon reduction potential of developing "good-quality" highways vis-a-vis the "poorly-maintained" highways with a focus on the emissions during the operational phase. To compare this carbon reduction potential with the carbon contribution during construction and / or maintenance in order to make a case for "good-quality" highways from a carbon perspective. To estimate the costs of establishing "good-quality" highways and calculate the carbon abatement cost in the highways sector. To compare the same with carbon abatement costs in other sectors.

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[1] Indicative considerations for carbon foot printing: Construction phase: Onsite fuel use (diesel, furnace oil and LDO) in construction technologies and ancillary equipment, carbon embodied in construction material and transportation of such materials; Operational phase: Carbon content of different fuels used, vehicle composition, vehicle's consumption per km of travel and distance travelled by vehicle population; and Maintenance phase: Onsite fuel use, materials for repair & maintenance and transportation of materials.

[2] Indicative considerations for carbon reducing interventions: Planning & design phase: Reduced travel distance in alignment planning, choice of energy-efficient technologies and low-carbon embodied material of construction & maintenance; Construction phase: Energy-efficient construction technologies, adoption of fuel management as a part of construction and use of low-carbon embodied material; Operational phase: Highway demand management, highway system management and vehicle improvement (incl. fuel economy). Maintenance phase: Energy-efficient maintenance practices, adoption of fuel management as a part of management and use of low-carbon embodied material.

4. To recommend strategies, policies and enabling actions that MoRTH would need to implement in order to mainstream no or low carbon approaches in highways at the planning, design, operation and maintenance phases. And, to recommend how these are to be ushered into the fabric of national highways management in India.

5. To provide a list of references to all the literature - both international and within India - that were used during the conduct of this study.

Part 2: Enhancing climate resilience of highways

1. To describe the prevailing context, both globally and within India, about the importance of building climate resilience across all economic sectors in general, and in the highways sector in particular.

2. To broadly outline the potential impacts of various climate-induced events / considerations on highways. The climate induced events / considerations range shall include but not be limited to sea level rise, storm surge, increase in intense precipitation, increase in cyclone / storm intensity, increase in wind speeds, increase in landslides in hilly areas and drought conditions in drier geographical areas.

3. To propose an approach (or approaches) to carry out a climate vulnerability assessment including the possible data sources to be used to models / scenarios that can be referred in order to determine the anticipated impact on highways due to climate-induced events. To administer these approaches in two selected highways as examples to demonstrate how these assessments are to be done.

4. To identify and list comprehensively climate-resilient interventions, both engineering and non-engineering, that are relevant in the planning, design, construction, operation and maintenance phases of the highway project. These should necessarily cover the context, e.g. coastal areas, hilly / mountainous areas and drought-prone areas, within which the exacerbated climate-induced events will impact the highways.

5. To classify these climate-resilient interventions in the list as no-regrets, low-regrets and others in terms of costs if dealt with in advance. To provide ballpark cost estimates of these interventions, and to indicate them as absolute numbers or as a percentage of total project cost. To compare these costs with those that would be incurred post-climate induced event, if any, and to provide justifications.

6. To recommend strategies, policies and enabling actions that MoRTH would need to implement in order mainstream climate resilience in highways at the planning, design, operation and maintenance phases. And, to recommend how these are to be ushered into the fabric of national highways management in India.

7. To provide a list of references to all the literature - both international and within India - that were used during the conduct of this study.

Common to both parts

8. To conduct two national level stakeholder workshops in Delhi- one at the interim stage and second after the draft final report is ready – to present the findings and obtain feedback from the stakeholders. The stakeholders include the client, Government and relevant agencies, non-governmental organizations, representative of civil societies, private sector, funding agencies and international financial institutions.

Annexure 14: Review of Various Life Cycle Analysis Tools

Life cycle analysis tools currently available

S. No.	Software tool/Model	Developer	Details	Phase covered for CO_2 emissions estimation
1	HDM-4 (2006) Version-2	World Bank, USA	HDM-4 software is an analytic decision making tool based on life cycle cost used for economic evaluation of investment decisions on road projects. Through HDM-4 run, values of Economic Indicators are derived from the cost-benefit stream.	Construction , Maintenance and Operation
2	Calculator for Harmonised Assessment and Normalisation of Greenhouse Gas Emissions for Roads (CHANGER)	International Road Federation, USA	'CHANGER software adopts an input-output modelling methodology for estimating GHG emissions from road projects. The calculation model is based on a set of equations that enable assessment of overall emissions (output) generated by each source that has been identified and quantified (input)' (IRF).	Construction and Maintenance
3	Roads emission and optimisation (ROADEO) (2011) Version -1.2	World Bank, USA	ROADEO is developed as a spread sheet without any macro. This model is used for the evaluation of GHG emissions and access alternate construction practice to limit GHG emissions. (World Bank, 2011).	Construction and Maintenance
4	AFD Tool (2011) Version-2	Agence Française de Développement, France	It is a spread sheet model that uses projects /activity's operational data to estimate GHG emissions. The GHG calculations are done by creating an inventory of the activities carried out during the project. The quantities of materials used are entered in the spread sheet directly, that computes each item's emissions in carbon dioxide equivalents (CO_2e) via a scientifically determined 'emission factor' embedded in the spread sheet (AFD, 2011).	Construction and Maintenance
5	Project carbon calculator (2009) Version- 2	Royal BAM Group, Netherlands	'The Project Carbon Calculator calculates the CO_2 emissions on construction sites by examining a number of different categories, like material, construction site equipment, waste, etc. at the construction site. To calculate the CO_2 emissions of each of the categories, emission factors and assumptions are used. These emission factors and assumptions are in the document made available by reputable bodies' (BAM, 2009).	Construction
6	Highway Agency carbon tool (2015) Version- 1	Highway Agency, UK	The excel-based carbon tool is used to estimate emissions. When the data has been entered into the tool by the local/implementing agency, it is sent to Highways England where the carbon returns are processed and interpreted using standard carbon factors(Highways England, 2015).	Construction and Maintenance

7	ROAD-RES	Technical University of Denmark, Denmark	'ROAD-RES is a life cycle assessment model for road construction and disposal of residues, The model has two purposes: (i) To evaluate the environmental impacts and resource consumption in different life cycle stages of road construction with virgin materials and residues from waste incineration; (ii) To evaluate and compare two disposal methods for waste incineration residues, namely landfilling and utilization in road' (Birgisdóttir, 2005).	Construction and Maintenance
8	VIC-Roads	VIC-Roads, Australia	VIC-Roads is a macros enabled excel based life cycle assessment model for road construction. 'This model provides a means of estimating GHG emissions during the major road activities of construction, operation, and maintenance calculated over a 50 year life' (Transport Authorities Greenhouse Group, 2013).	Construction and Maintenance
9	Variways (2012) Version -2.1	Egis, France	'VARIWAYS is eco-comparison software that calculates the greenhouse gas emissions resulting from the manufacturing of materials, their transport and their placement for the main works categories (earthworks, pavements, path facilities, structures, tunnels and drainage) on the basis of the available reference databases as a function of the main characteristics of the project and its quantities' (IDRRIM, 2016). The emission factors are taken from Bilan Carbone method by ADEME/ABC and Inventory of Carbon and Energy (ICE) or of EcoInvent	Construction, Maintenance and Operation
10	ECORCE M (2014) Version - 2	IFSTTAR. France	ECORCE M, a Java 7 application tool, provides robust assessment for comparisons of construction/ maintenance scenarios using a set of mid-points indicators in the framework of LCA.[25]	Construction and Maintenance
11	Gaia.BE	Eurovia, UK	Gaia.BE is a software package that quantifies the environmental impact of a project based on life cycle analysis method. It breaks the project into different stages to access the impacts and calculates the impacts by the means of database comprising public information recognised by the industry and expertise provided by Eurovia's research centre.[26]	Construction and Maintenance
12	IRC-SP-30:2009	Indian Roads Congress, India	'IRC-SP-30:2009 is intended to help the highway planners and engineers in India to undertake economic evaluation of highway projects under non-urban conditions' (IRC-SP-30, 2009). It elaborates the technique of Benefit-Cost (B-C) analysis. In this method, Highway Economic Analysis, also known as Highway Project Appraisal, is carried out by evaluating the costs of and benefits from a scheme. These costs and benefits are quantified over a selected time horizon and evaluated by a common yardstick.	Construction, Maintenance and Operation

Note: Other emission estimation tools were also explored as part of the study; these include ADEME Methodology, Highway Agency Geotechnical Tool, and Imp Roads.

[25] http://ecorcem.ifsttar.fr/; last accessed on

[26] http://www.eurovia.com/media/181352/gaia_rv_gb_bd.pdf; last accessed on

Annexure 15: Snapshot of Project-level Construction and Maintenance Emissions Calculation Using TERI's Excel Model

Snapshot of emissions during Construction phase of a sample National Highway

Select the Sections for which data is to be enetered			
☑ Construction	☑ Maintenance (Annual)	☑ Maintenance (Periodic)	☑ Operations

Project Details			
Highway Type	Plains		
Project Name	RAEBARELI-BANDA NH-232		
State	Uttar Pradesh	Life of Project	15
Name of Officer In Charge		Name of Contractor (Year)	Theme Enginering
Road Details			
Chainage Start	km 152.533	Chainage End	km 285.818
Total Length (KM)	133		
Cross Section Details			
No. of lanes	2	Row	20
Median Width	Undivided	Sub Type	Plain
Shoulder Width	1	Construction Type	Bitumen
Service Road Width			

	Total Embodied Energy In MJ	Total Carbon Emissions In Tonnes CO_2 Lifetime
Material and Fuel Usage	1,86,48,04,505	66,602
Movement of Fuel and Material	26,71,50,380	24,044
Movement of Labour	3,271	0
Contruction Phase Total	**2,13,19,58,156**	**90,646**
Periodic Maintenance	0	0
Annual maintenance	0	0
Maintenance Total	**0**	**0**
Operational Total	**0**	**0**

Figures in lane km per year	Total Embodied Energy In MJ per Year per Lane Km	Total Carbon Emissions In Tonnes CO_2 per Year per Lane KM
Material and Fuel Usage	4,67,370	17
Movement of Fuel and Material	66,955	6
Movement of Labour	218	0
Contruction Phase Total	**5,34,543**	**23**
Periodic Maintenance	0	0
Annual maintenance	0	0
Maintenance Total	**0**	**0**
Operational Total	**0**	**0**

Total Emission (Lifetime) (tCO2)	90,646
Total Emission per LaneKM (Lifetime) (tCO2/lane km)	341
Total Emission per LaneKM per Year (tCO2 per lane km/year)	23

Snapshot of emissions during Construction phase of a sample National Highway (…Continued)

Construction Phase information			
Construction Type	Bitumen	Pavement T	Flexible
No. Of Lanes for Construction Phase	2	Constructio	78.55
Start Date		End Date	01-Oct-2016

Table5

Construction Phase

CONSTRUCTION MATERIALS AND FUELS

Construction materials used	Unit	Quantity	Source	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle (in specified units)	No. of trips (from source to site)	Fuel type (diesel, CNG, etc.) of vehicle	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/unloading (hours)	Total EE (MJ)	Total CO2 (kg)
Soil brought to site from outside	tonnes	2,17,770	Multiple Locations	1	Dumper	20	10,889	Diesel	2.5	0.25	407662	36690
Soil removed from site (not used on site)	tonnes	92,232	Near by Area	0.2	Dumper	20	4,612	Diesel	2.5	0.25	83901	7551
Natural Sand	tonnes			15	MAV	20	-	Diesel	3	0.25		
Moorum	tonnes			15	MAV	20	-	Diesel	3	0.25		
Gravel	tonnes	5,05,145	Kabrai	165	Truck	40	12,629	Diesel	2.5	0.5	50467371	4542063
Laterite	tonnes			15	MAV	20	-	Diesel	3	0.25		
Kankar	tonnes			15	MAV	20	-	Diesel	3	0.25		
Brick metal/ Jhama	tonnes			15	MAV	20	-	Diesel	3	0.25		
Crushed stones	tonnes			15	MAV	20	-	Diesel	3	0.25		
Crushed slag	tonnes			15	MAV	20	-	Diesel	3	0.25		
Reclaimed Concrete	tonnes			15	MAV	20	-	Diesel	3	0.25		
Cement lime/ limestone dust, etc	tonnes			15	MAV	20	-	Diesel	3	0.25		
Bricks	tonnes			15	MAV	20	-	Diesel	3	0.25		
Coarse Aggregate	tonnes	8,03,616	Kabrai	165	Truck	40	20,090	Diesel	2.5	0.5	80286624	7225796
Fine aggregate	tonnes	1,300	Uthi	67	Truck	40	33	Diesel	2.5	0.5	53255	4793
Water	Litres	1,44,000	Near Camp	35	Tanker	12000	12	Diesel	3	0.25	8581	772
Ordinary Portland Cement	tonnes	8,350	Lucknow	100	Truck	35	239	Diesel	2.5	1	586716	52804
Portland-Pozzolana Cement	tonnes			15	MAV	20	-	Diesel	3	0.25		
Portland Slag Cement	tonnes			15	MAV	20	-	Diesel	3	0.25		
Chemical Admixture	tonnes	45	Delhi	650	Truck	15	3	Diesel	2.5	2	47233	4251
Fly Ash	tonnes			15	MAV	15	-	Diesel	3	0.25		
Granulated Blast Furnace Slag	tonnes			15	MAV	20	-	Diesel	3	0.25		
Silica Fume	tonnes			15	MAV	20	-	Diesel	3	0.25		
Ready mix concrete*	tonnes	61,536	Camp	35	Truck mixer	14.4	4,273	Diesel	2	0.2	4543518	408917
Steel reinforcement	tonnes	1,370	Kanpur	110	Trailer	35	39	Diesel	1.5	2	176832	15915
Other steel	tonnes			15	MAV	20	-	Diesel	3	0.25		
Concrete curing compound	tonnes	2	Kanpur	110	Tempo	1.5	1	Diesel	10	0.5	688	62
Pre-Molded Joint Filler	tonnes			15	MAV	20	-	Diesel	3	0.25		
Joint Sealing	Litres			15	MAV	20	-	Diesel	3	0.25		
Steel or polymeric synthetic fibers	tonnes			15	MAV	20	-	Diesel	3	0.25		
Bitumen/ Tar	tonnes	13,100	Mathura	572	Tanker	20	655	Diesel	2.5	1	9048481	814363
Cationic bitumen emulsion	tonnes	1,050	Mathura	572	Tanker	14	75	Diesel	2.5	1	1036086	93248
Ready-made Premix material not mixed at project site if any (specify whether hot/cold/warm)*	tonnes	2,72,670	Camp	35	Dumper	24	11,361	Diesel	2.5	1.5	10478574	943072
Elastomers	Litres			15	MAV	20	-	Diesel	3	0.25		
Paint	Litres			15	MAV	20	-	Diesel	3	0.25		
Primer	Litres			15	MAV	20	-	Diesel	3	0.25		
Materials for formwork	tonnes			15	MAV	20	-	Diesel	3	0.25		
In case, NH section has sidewalk/ pavement (in urban areas), - Precast cement concrete slabs	tonnes			15	MAV	20	-	Diesel	3	0.25		
- Stone slabs	tonnes			15	MAV	20	-	Diesel	3	0.25		
FUEL/POWER												
On site electricity	Units			NA	NA	NA	NA	NA	NA	NA		
Diesel (generators)	Litres			15	MAV	12	-	Diesel	3	0.25		
Diesel (machinery &vehicles)	Litres	2,89,470	IOCL Mathura	572	Tanker	6000	48	Diesel	3	0.25	553893	49850
Petrol	Litres			15	MAV	12	-	Diesel	3	0.25		
CNG	tonnes			15	MAV	12	-	Diesel	3	0.25		
Furnace oil	Litres			15	MAV	20	-	Diesel	3	0.25		
LDO	Litres			15	MAV	20	-	Diesel	3	0.25		
Kerosene	Litres			15	MAV	20	-	Diesel	3	0.25		
LPG	Litres			15	MAV	10	-	Diesel	3	0.25		
Natural gas	tonnes			15	MAV	10	-	Diesel	3	0.25		
Biomass	tonnes			15	MAV	10	-	Diesel	3	0.25		

STREET FURNITURE

Type	Quantity per km (numbers. Etc)	Primary materials of which street furniture is made (steel, aluminum	Weight of primary materials per fixture (if available)	Manufacturer	Source from where street furniture is/was brought: Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)	Number of trips	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/unloading (hours)		
Signages					400	MAV	570	Diesel	0	3	0.25		
Street lights					400	MAV	75	Diesel	0	3	0.25		
Toll gates					400	MAV	100	Diesel	0	3	0.25		
Bus stop shelter (if any)					400	MAV	950	Diesel	0	3	0.25		
Road delineators					400	MAV	100	Diesel	0	3	0.25		
Traffic signals					400	MAV	100	Diesel	0	3	0.25		
Others: (Specify)					400	MAV	100	Diesel	0	3	0.25		

MOVEMENT OF PERSONNEL/ LABOUR

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily): Vehicle type	Fuel type	Average occupancy	Average daily distance travelled to reach construction site (kms)		
Contractors/engineers/ other staff	4	LMV	Diesel	5	52.5	147	13
Construction labour	50	Mini Truck	Diesel	15	35	408	37
Equipment operators	15	Bike	Diesel	2	52.5	1377	124

Snapshot of emissions during Construction phase of a sample National Highway (…Continued)

Select the Sections for which data is to be eneterered			
☑ Construction	☑ Maintenance (Annual)	☑ Maintenance (Periodic)	☑ Operations

Table 2

Project Details			
Highway Type	Plains		
Project Name	Bhubneshwar-Ichapuram NH-16		
State	Odisha	Life of Project	20
Name of Officer In Charge	MR. V. BANSAL, I	Name of Contractor (Year)	SHREE JAGANNATH EXPRESSW
Road Details			
Chainage Start		Chainage End	
Total Length (KM)	185		
Cross Section Details			
No. of lanes	4	Row	60
Median Width	1.8	Sub Type	Coastal
Shoulder Width	1.5	Construction Type	Bitumen
Service Road Width	3		

	Total Embodied Energy In MJ	Total Carbon Emissions In Tonnes CO_2 Lifetime
Material and Fuel Usage	0	0
Movement of Fuel and Material	0	0
Movement of Labour	0	0
Contruction Phase Total	**0**	**0**
Periodic Maintenance	1,62,84,31,234	22,185
Annual maintenance	35,98,30,153	22,490
Maintenance Total	**1,98,82,61,387**	**44,675**
Operational Total	**0**	**0**

Figures in lane km per year	Total Embodied Energy In MJ per Year per Lane Km	Total Carbon Emissions In Tonnes CO_2 per Year per Lane KM
Material and Fuel Usage	0	0
Movement of Fuel and Material	0	0
Movement of Labour	0	0
Contruction Phase Total	**0**	**0**
Periodic Maintenance	1,10,029	1
Annual maintenance	24,313	2
Maintenance Total	**1,34,342**	**3**
Operational Total	**0**	**0**

Total Emission (Lifetime) (tCO2)	44,675
Total Emission per LaneKM (Lifetime) (tCO2/lane km)	60
Total Emission per LaneKM per Year (tCO2 per lane km/year)	3

Snapshot of emissions during Periodic Maintenance of a sample National Highway

Maintenance Phase information			
Construction Type	Bitumen	Pavement Type	Flexible
No. Of Lanes for Maintenance Phase	4	Maintenance Length (KM)	78.126
Periodic maintenance frequency (Years)	7		

Table7

Maintenance Phase

ANNUAL MAINTENEANCE

PERIODIC MAINTENEANCE

CONSTRUCTION MATERIALS AND FUELS

Construction materials used	Unit	Quantity	Source	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle (in specified units)	No. of trips (from source to site)	Fuel type (diesel, CNG, etc.) of vehicle	Fuel efficiency (km/l) of vehicle	Avg. idling time while loading/unloading (hours)	Total EE (MJ)	Total CO2 (kg)
Soil brought to site from outside	tonnes			15	MAV	20	0	Diesel	3			
Soil removed from site (not used on site)	tonnes			15	MAV	20	0	Diesel	3			
Natural Sand	tonnes			15	MAV	20	0	Diesel	3			
Moorum	tonnes			15	MAV	20	0	Diesel	3			
Gravel	tonnes			15	MAV	20	0	Diesel	3			
Laterite	tonnes			15	MAV	20	0	Diesel	3			
Kankar	tonnes			15	MAV	20	0	Diesel	3			
Brick metal/ Jhama	tonnes			15	MAV	20	0	Diesel	3			
Crushed stones	tonnes			15	MAV	20	0	Diesel	3			
Crushed slag	tonnes			15	MAV	20	0	Diesel	3			
Reclaimed Concrete	tonnes			15	MAV	20	0	Diesel	3			
Cement lime/ limestone dust, etc	tonnes			15	MAV	20	0	Diesel	3			
Bricks	tonnes			15	MAV	20	0	Diesel	3			
Coarse Aggregate	m3	18,890	Local quarry	40	MAV	20	944.5	Diesel	3	0.25	770053	69305
Fine aggregate	m3	8,872	Local quarry	40	MAV	20	443.6	Diesel	3	0.25	361668	32550
Water	Litres	20,000	Local	5	Tanker	12000	1.666666667	Diesel	3	0.25	189	17
Ordinary Portland Cement	tonnes			15	MAV	15	0	Diesel	3			
Portland-Pozzolana Cement	tonnes			15	MAV	20	0	Diesel	3			
Portland Slag Cement	tonnes			15	MAV	20	0	Diesel	3			
Chemical Admixture	tonnes			15	MAV	13	0	Diesel	3			
Fly Ash	tonnes			15	MAV	15	0	Diesel	3			
Granulated Blast Furnace Slag	tonnes			15	MAV	20	0	Diesel	3			
Silica Fume	tonnes			15	MAV	20	0	Diesel	3			
Ready mix concrete*	tonnes			15	MAV	6	0	Diesel	3			
Steel reinforcement	tonnes			15	MAV	15	0	Diesel	3			
Other steel	tonnes			15	MAV	20	0	Diesel	3			
Concrete curing compound	tonnes			15	MAV	20	0	Diesel	3			
Pre-Molded Joint Filler	tonnes			15	MAV	20	0	Diesel	3			
Joint Sealing	Litres			15	MAV	20	0	Diesel	3			
Steel or polymeric synthetic fibers	tonnes			15	MAV	20	0	Diesel	3			
Bitumen/ Tar	tonnes	4,117	Haldia	450	MAV	20	205.85	Diesel	3	0.25	1859851	167387
Cationic bitumen emulsion	tonnes	360	Haldia	450	MAV	12	30	Diesel	3	0.25	271049	24394
Ready-made Premix material not mixed at project site if any (specify whether hot/cold/warm)*	tonnes			15	MAV	20	0	Diesel	3			
Elastomers	Litres			15	MAV	20	0	Diesel	3			
Paint	Litres	33,198	Bhubaneshwar	60	MAV	6000	5.533	Diesel	3	0.25	6730	606
Primer	Litres			15	MAV	20	0	Diesel	3			
Materials for formwork	tonnes			15	MAV	20	0	Diesel	3			
In case, NH section has sidewalk/ pavement (in urban areas), - Precast cement concrete slabs	tonnes			15	MAV	20	0	Diesel	3			
- Stone slabs	tonnes			15	MAV	20	0	Diesel	3			
FUEL/POWER												
	Units			NA	NA	NA	NA	NA	NA	NA		
Diesel (generators)	Litres			15	MAV	12	0	Diesel	3	0.25		
Diesel (machinery &vehicles)	Litres	8,000	Local market	20	MAV	6000	1.333333333	Diesel	3	0.25	552	50
Petrol	Litres	5,000	Local market	20	MAV	6000	0.833333333	Diesel	3	0.25	345	31
CNG	Litres			15	MAV	12	0	Diesel	3	0.25		
Furnace oil	Litres	19	Haldia	450	MAV	20	0.95	Diesel	3	0.25	8583	772
LDO	Litres			15	MAV	20	0	Diesel	3	0.25		
Kerosene	Litres			15	MAV	20	0	Diesel	3	0.25		
LPG	Litres			15	MAV	10	0	Diesel	3	0.25		
Natural gas	Litres			15	MAV	10	0	Diesel	3	0.25		
Biomass	Litres			15	MAV	10	0	Diesel	3	0.25		

MOVEMENT OF PERSONNEL/ LABOUR

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)			
		Vehicle type	Fuel type	Average occupancy				
Contractors/engineers/ other staff	5	Four wheeler	Diesel	5	40		140	13
Construction labour	20	Two wheeler	Diesel	2	20		699	63
Equipment operators	10	Two wheeler	Diesel	2	10		175	16
Workmen	30	Two wheeler	Diesel	2	20		1049	94
		LMV	Diesel	5	30			

Annexure 16: Emissions Related to a Detailed Terrain-wise Classification

To understand the difference in emissions that could occur on account of better data i.e. lane km division into plain, hilly, desert and coastal, TERI carried out a rough analysis to derive the lane km distribution across all these terrains. The resultant distribution of lane km is as follows:

- Plains - 77%
- Hilly - 7%
- Coastal - 13%
- Desert - 3%

TERI estimated the NH network emissions (construction and maintenance emissions) using the above distribution for comparison purpose, the results of which are depicted below.

Emissions when only two terrains are considered – Plains and Hilly

Based on two terrain classification, which is also mentioned in Section 3.3, total CO_2 emissions from the National Highway sector on account of construction and maintenance activities is estimated to be about 7.8 MT during 2016.

Emissions during construction and maintenance on account of National Highways in Plains and Hilly terrains (million tonnes CO_2e)

Phases	Plains	Hilly	Total
Construction	4.98	0.64	5.62
Maintenance	2.13	0.05	2.18
Total	**7.11**	**0.69**	**7.80**

Source: TERI Estimates

Emissions when four terrains are considered – Plains, Hilly, Coastal and Desert

Considering broad classification of National Highways under four terrain types, total CO_2 emissions is estimated to be about 12.27 MT, which is 1.6 times higher than the *two terrain* analysis mentioned above. The higher emission estimate under this could be explained by the higher emission coefficient of coastal NHs due to larger number of structures (bridges, culverts, etc.) and resultant material usage.

Emissions on account of construction and maintenance activities for National Highways in Plains, Coastal, Hilly and Desert Terrains (million tonnes CO_2e)

Phase	Plains	Hilly	Coastal	Desert	Total
Construction	4.00	1.15	4.85	0.37	10.37
Maintenance	1.71	0.09	0.09	0.02	1.90
Total	5.71	1.24	4.94	0.39	12.27

Source: TERI Estimates

The Energy and Resources Institute