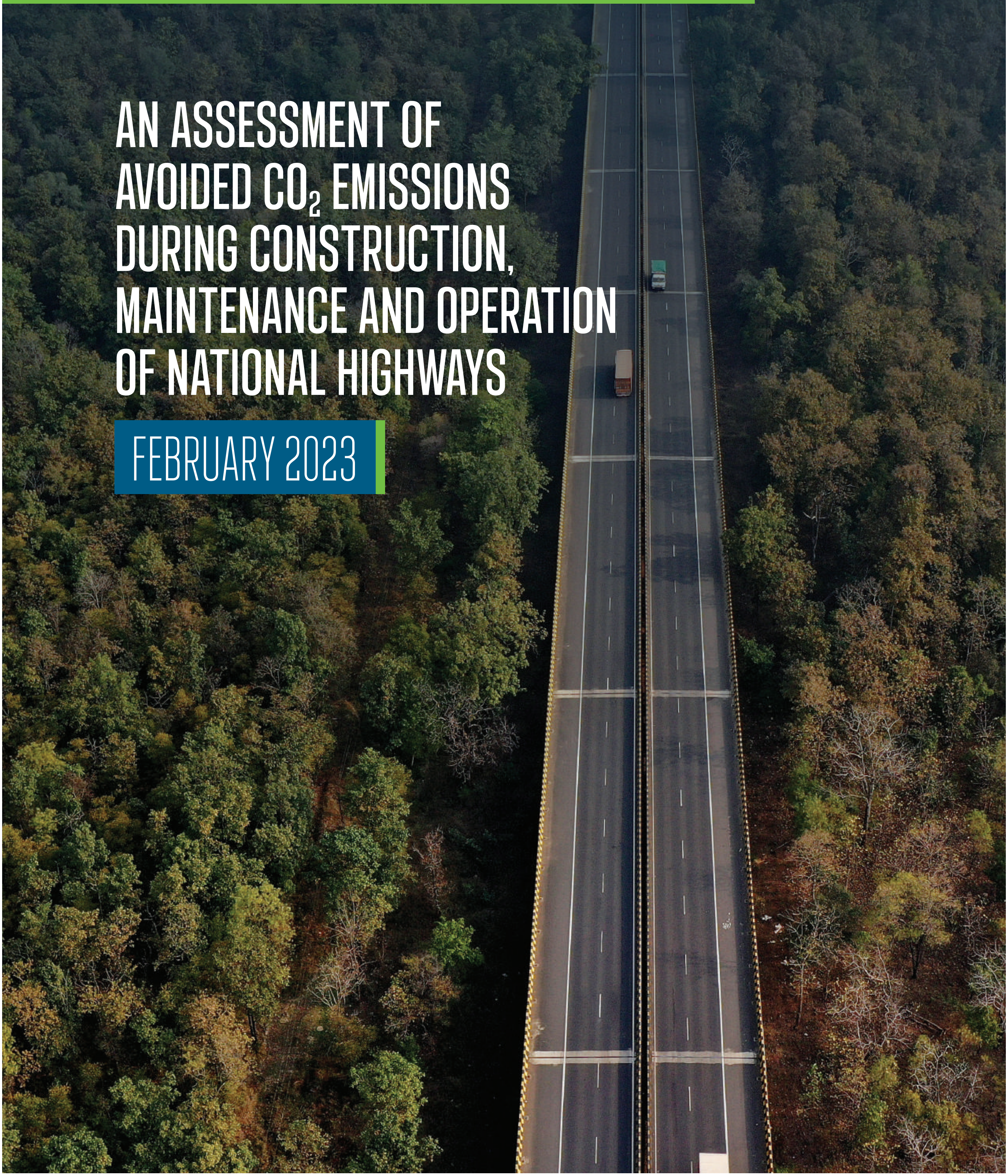

AN ASSESSMENT OF AVOIDED CO_2 EMISSIONS DURING CONSTRUCTION, MAINTENANCE AND OPERATION OF NATIONAL HIGHWAYS

FEBRUARY 2023

CSIR CRRI | IORA Ecological Solutions | Creating Future Fuels | teri

Keeping India's climate commitments and goals in mind against the backdrop of highways as enablers of development, a rapid assessment was carried out to quantify the potential emissions of CO_2 per km that can be avoided by the National highway operations. Using existing data available with the National Highways Authority of India (NHAI) and in consultation with experts from Ministry of Environment, Forest and Climate Change (MoEFCC), the report has been jointly prepared by CSIR-Central Road Research Institute ("CSIR-CRRI"), CSIR-Indian Institute of Petroleum ("CSIR-IIP"), IORA Ecological Solutions ("IORA") and The Energy and Resources Institute ("TERI").

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Executive Summary

India has the 2nd longest road network in the world. Amongst the different types of roads, the National Highways (NH) extending to 1,44,634 km[1] till date has contributed significantly to India's rapid economic development. Between 2014 and January 2023, more than half of the existing highways (~77,265 kms)[2] have been added. This rapid pace of construction of highways is enabling integration of the local economies of far flung towns and villages into the national economy.

Construction and maintenance of roads is known to be a source of CO_2, which is over and above the CO_2 emitted from fuel operated vehicles on roads. In 2016, about 243.00 million tons of CO_2 was emitted from the operation of fossil fuel run vehicles in India, which is 10.8% of the total national CO_2 emissions.[3] The new and improved state of the art NH replacing congested and often circuitous routes, however, can help avoid CO_2 emissions by reducing fuel combustion in vehicles plying on them. The avenue plantations and compensatory afforestation's (CA) can additionally sequester CO_2, thus adding to the offset of CO_2 emitted from highway operations as a whole.

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1 https://pib.gov.in/PressReleseDetailm.aspx?PRID=1888480#:~:text=As%20on%2030%20November%202022,country%20was%201%2C44%2C634%20km.

2 Provided by NHAI

3 India's BUR3 report to UNFCCC, 2021. Accessed on 7th Sep., 2022 from https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

This report presents a methodology for assessing the extent of CO_2 that can be avoided per km of operational highways. Data from 20 NH stretches together extending to a length of 2,191.5 kms and located in India's diverse climate zones and topography have been applied to estimate the potential CO_2 that can be avoided by the NH. Of the 20 NH stretches considered, 5 are greenfield and 15 are brownfield. The results of this assessment indicates that:

1. Construction of all 20 stretches together have led to an emission of 5,716.66 thousand tonnes of CO_2 and maintenance has led to an emission of 1,164.68 thousand tCO_2
2. Felling of trees outside forests and removal of forests done to pave the way for construction of the highways has led to the emission of 652.60 thousand tCO_2.
3. Fuel consumption by vehicles would have been 50.96 billion litres in a 20 year period if BAU conditions of highways persisted. In the BAU case, the share of petrol in the total fuel consumption would have been 17-19% and diesel share would have been 81-83%.
4. In the Improvement case, when the new highways are operational, it is estimated that the total fuel consumption would be about 41.16 billion litres in a 20 year period. This amount of consumption is less by 19% or 9.77 billion litres of fuel is saved in the improvement case as compared to the BAU case.
5. In the total fuel savings, share of petrol will be about 7% and rest will be share of diesel. The major savings will be 53% and 23% by MCVs and HCVs respectively.
6. For the 20 NH stretches, the savings in petrol range from 2% to 21%, and diesel saving ranges from 1% to 42%. This variation is mainly due to variable conditions of the highways vis a vis their road characteristics (width, roughness etc.) and wide ranging traffic volumes and share of different vehicle types.
7. Therefore due to vehicles plying on the newly constructed and improved highways, it is estimated that in a 20 year period about 25.19 million tonnes of CO_2 will be avoided along the entire 2,191.54 kms of NH stretches, which is equivalent to an avoidance of 11,493 tonnes of CO_2 per km in 20 years.
   a. In case of Greenfield Highways improvements, the CO_2 avoidance in 20 years can be of the order of 10,167 tonnes per km whereas
   b. Improvements of Brownfield Highways can result in about 11,936 tonnes per km of CO_2 avoidance.
8. It is estimated that the avenue plantations and compensatory afforestation (CA) done post construction of the highways together potentially can sequester 584.27 thousand tonnes of CO_2 over a 20 year period.
9. Adding up the CO_2 emissions and sequestrations streams across all the stretches considered that together extend to a total of 2,191.54 kms, it is estimated that potentially 18,236.62 thousand tonnes of CO_2 over a 20 year period can be avoided. This is equivalent to a potential avoidance of 8321 tonnes CO_2 per km.
10. Based on standard assumptions, it is estimated that a total of 18,237.31 thousand tonnes of CO_2 emissions avoided across 2191.54 kms of NH in a 20-year period is equivalent to CO_2 sequestered by 45.14 million trees.
11. A total of 77,265 kms of national highway has been constructed till date since 2014 which can together potentially avoid 32.15 million tonnes of CO_2 annually and 642.95 million tons of CO_2 cumulatively in next 20 years. This is equivalent to CO_2 sequestration by 31,826 million trees.

The detailed guidance for estimating tonnes of CO_2 avoided per km of NH presented in this report can form the basis for tracking CO_2 emitted or avoided due to this activity. For the per km CO_2 avoided estimates to be more scientifically rigorous, systematic collation of observations post construction of NHs is suggested to be carried out and made available along with pre-NH construction data contained in the relevant EIAs and DPRs. Further to continuously enhance avoidance of CO_2 emissions from this sector, it is suggested to develop commensurate standard decision tree based location specific SOPs that would integrate the best available green technologies in the entire cycle of NH construction, operation and maintenance.

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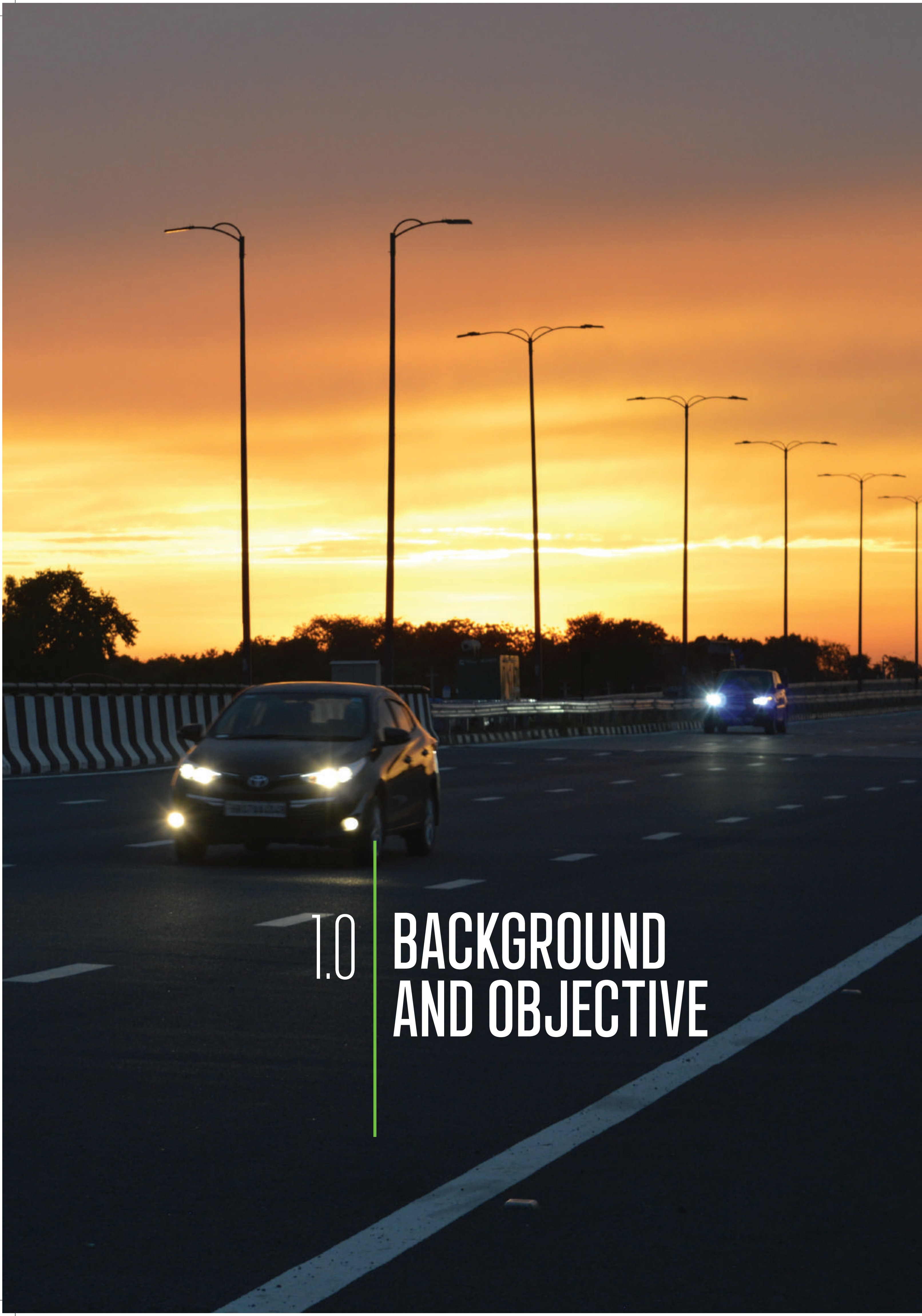
List of Abbreviations

AGB	Above Ground Biomass
ARAI	Automotive Research Association of India
BAU	Business As Usual
BGB	Below Ground Biomass
CA	Compensatory Afforestation
CRRI	Central Road Research Institute
DPR	Detailed Project Reports
EIA	Environment Impact Assessment
EIO	Environmental Input-Output
EPE	Eastern Peripheral Expressway
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSB	Granular Sub Base
HCV	Heavy 2/3 axle Commercial Vehicles
IIP	Indian Institute of Petroleum
IPCC	Intergovernmental Panel on Climate Change
IRC	Indian Road Congress
ISO	International Organization for Standardisation
km	Kilometre
kmpl	Kilometre per litre
LCA	Life Cycle Analysis
LCV	Light Commercial Vehicles
MCV	Multi-axle Commercial Vehicles
MoEFCC	Ministry of Environment, Forest and Climate Change
MTW	Motorized Two Wheelers
NCV	Net Calorific Value
NH	National Highways
NHAI	National Highways Authority of India
NPV	Net Present Value
PCU	Passenger Car Units
PDD	Project Design Documents
PQC	Pavement Quality Concrete
SOC	Soil Organic Carbon
tCO_2	tonnes CO_2
TERI	The Energy and Resources Institute
ToF	Trees felled Outside Forests



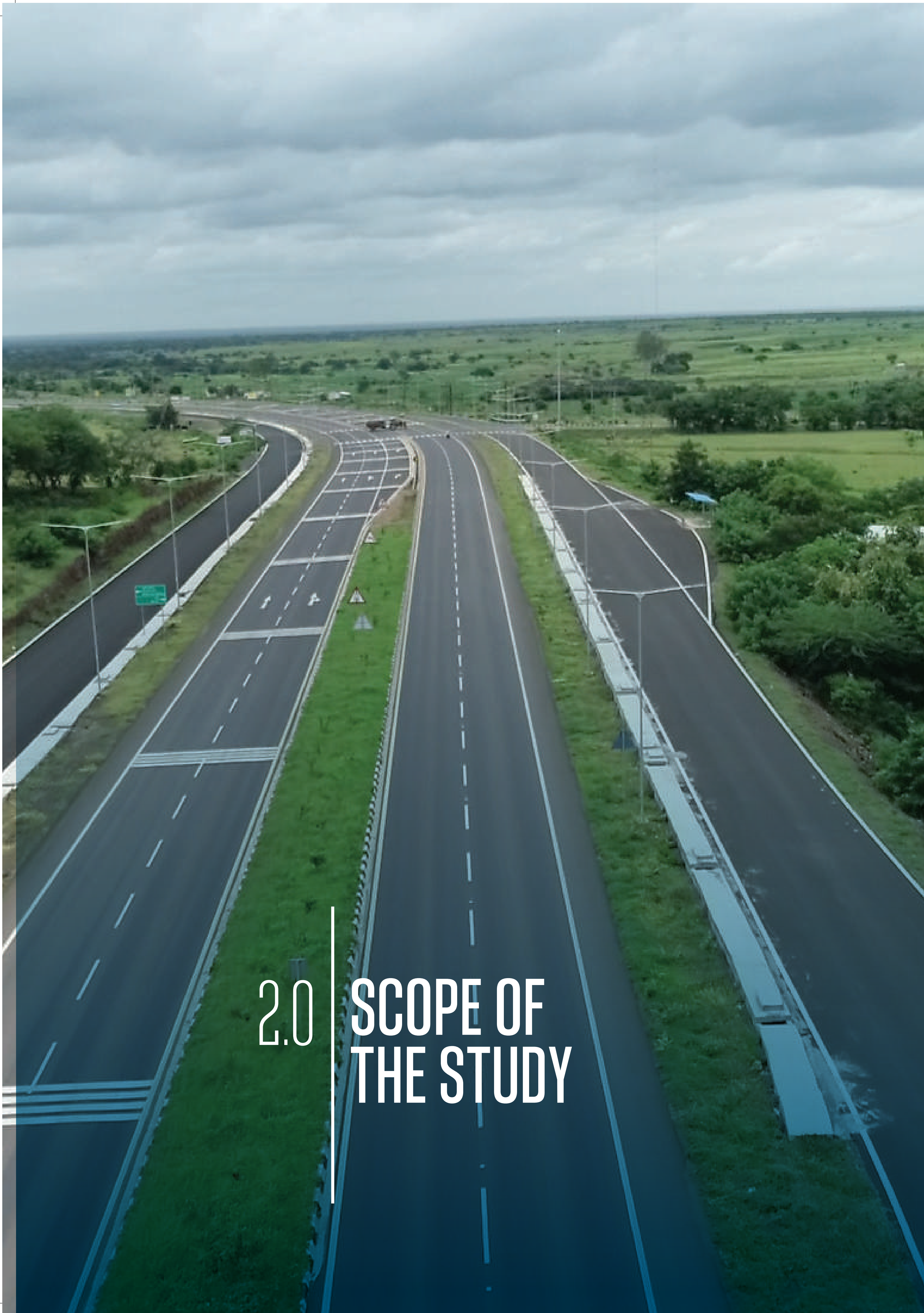
1.0 BACKGROUND AND OBJECTIVE

India is rapidly connecting all its states and union territories with National Highways (NH). Presently, about 37 km of NH are being added every day, and it is envisaged that by 2025 there will be about 1,80,000 km of world-class NH crisscrossing the country, connecting all its states and union territories.

Such construction activities are often perceived as sources of greenhouse gas (GHG) emissions, whereas improved highway capacity and quality may also reduce GHG emissions due to improvements in traffic operations (reduced congestion and reduced stop-and-go driving), travel distance and time reduction between cities, and improvements in road surface characteristics.

India has voluntarily committed to reduce the GHG emission intensity of its Gross Domestic Product (GDP) by 45% below 2005 levels by 2030. Further, it targets to become carbon neutral by 2070. Strategic green construction of new NH and expansion of old ones can significantly contribute to these mitigation targets of India. These commitments fall in line with the requirements of the Paris Agreement, to which India is a signatory. Further, with reference to IPCC studies and reports, it is important to develop a procedure and associated templates for estimating net GHG values with a reasonable degree of accuracy in the context of land-use changes that occur when agricultural land, forests, or trees outside forests are acquired for purposes of highway development in India.

This report presents a methodology for assessing the potential CO_2 that can be avoided and in view of this uses data of 20 highway stretches spanning 2,191.5 km located in diverse climate zones and topography in India to arrive at a CO_2 that can be avoided per km of NH stretches constructed. The methodology can form the basis for formulating norms of monitoring/tracking CO_2 emitted or avoided from NH constructed and hence can establish its contribution to India’s 2030 NDCs and 2070 Carbon neutral goals.



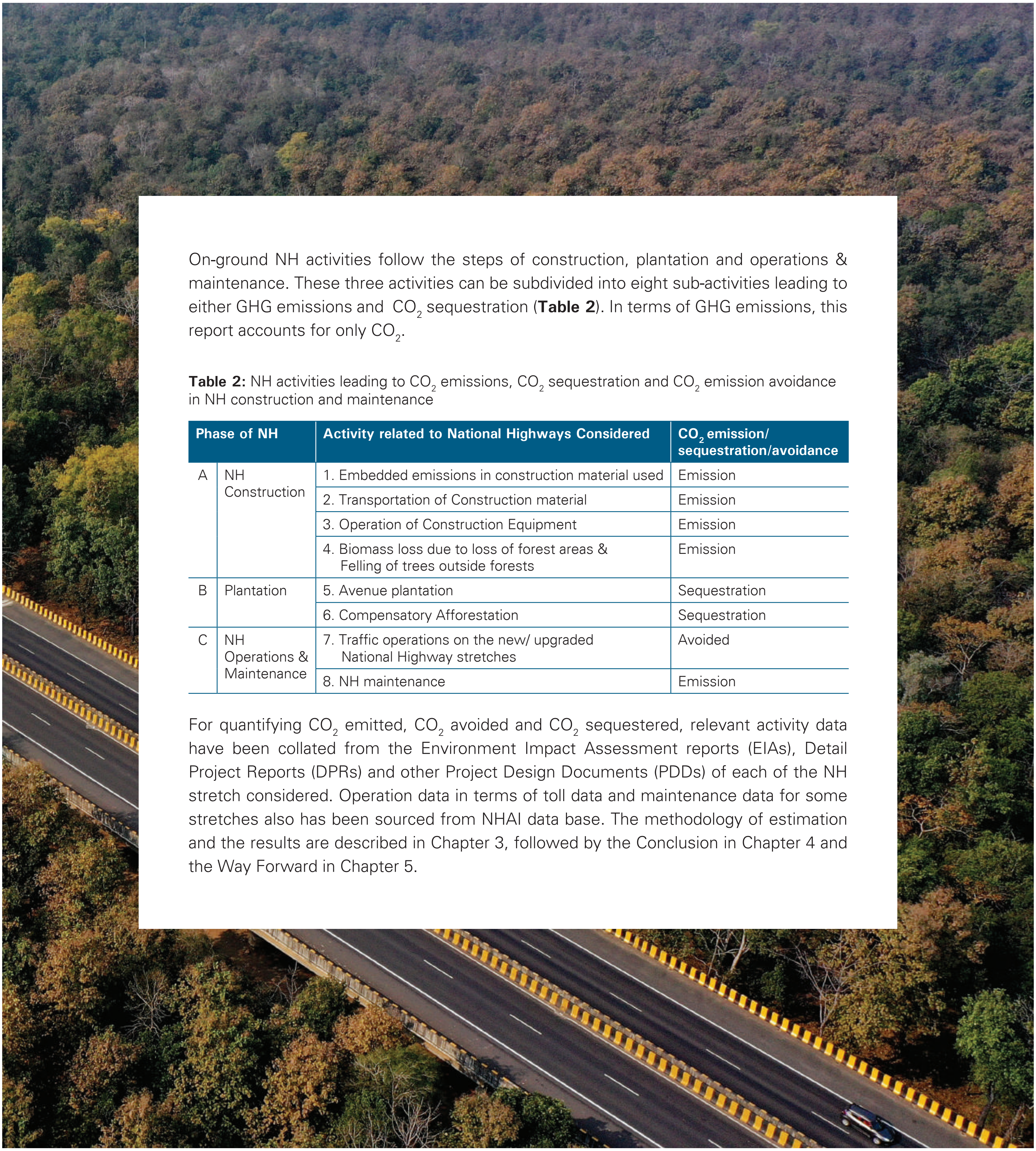
2.0 SCOPE OF THE STUDY

The twenty selected stretches of NH spanning 2,191.5 km are located in the mountainous regions of North and North-East, hilly regions of Western Ghats on the western coast, in Southern India, and in the eastern section of the Deccan plateau. The analysis is based on 5 greenfield highways that avoid inhabited areas and go through new alignments and 15 brownfield highways that essentially have widened/developed existing roads. **Table 1** below indicates the name, stretch length, number of lanes, and type of pavement.

Table 1: National Highway Stretches Considered

S. No.	NH Section	Length (km)	No. of Lanes	Pavement Type (BT/CC)
	Greenfield Stretches			
1	Eastern Peripheral Expressway (EPE) NE-2	136.0	6	CC
2	Ahmedabad-Vadodara Expressway (NE-1)	93.3	6	BT
3	Ismailabad-Narnual Section (Trans Haryana) NH-152D	227.0	6	BT
4	Delhi-Meerut Expressway (NE-3)	82.0	6/8	BT
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	2/4	BT, CC
	Brownfield Stretches			
6	Delhi -Agra Section (NH-2)	179.5	6 (4)	BT
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	4 (4)	BT
8	Panipat-Jalandhar Section (NH-44)	291.1	6 (4)	BT
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	4 (2)	CC
10	Yedeshi-Aurangabad Section (NH-52)	189.0	4 (2)	BT
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	4 (2)	BT
12	Pune Solapur Highway (Yavat-Temburni Section) NH-65	104.4	4 (2)	BT
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	4 (2)	BT
14	Guwahati to Nagaon Highway (Khanapara - Dharamtul Section) NH-27	66.6	4 (2)	BT, CC
15	Walayar (KL/TN border)-Edapally Section (NH-544)	124.6	4/6 (2)	BT
16	Porbandar-Dwarka Section (NH-51)	117.7	4 (2)	CC
17	Pasighat-Bomjur, Arunachal Pradesh (NH-13)	22.2	2 (1)	BT
18	Pasighat-Yingkiang Road (Singer River-Sizoh Nala Section), Ar.P (NH-513)	23.4	2 (1)	BT
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	6 (6)	BT
20	Banihal Jammu Highway (Quazigund-Banihal Section) NH-1A	22.5	4 (2)	BT
	Total	**2,191.5**		

Note: BT- Bituminous, CC- Concrete; Values in the parenthesis in No. of Lanes column represent the lanes before widening; Source: NHAI

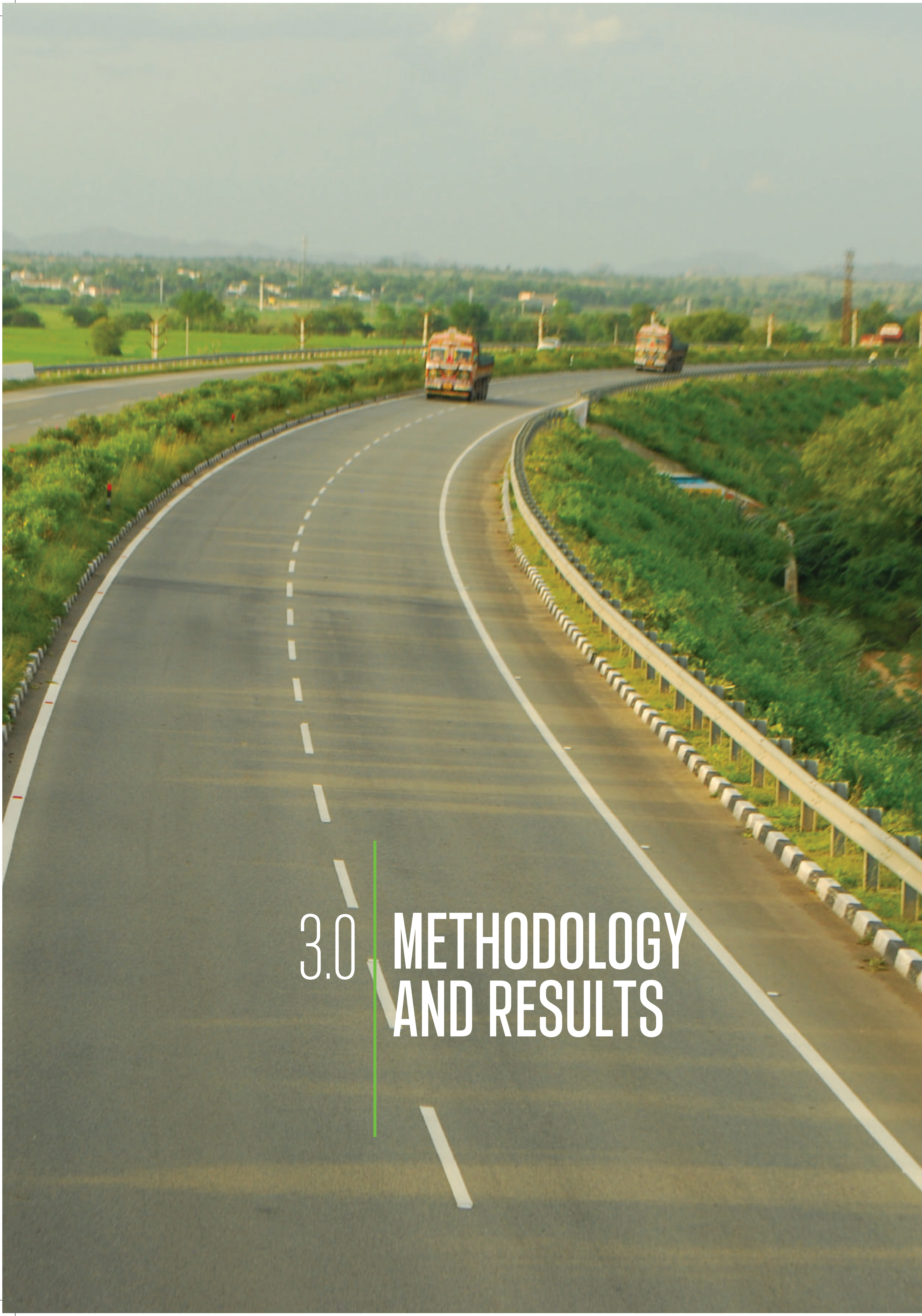


On-ground NH activities follow the steps of construction, plantation and operations & maintenance. These three activities can be subdivided into eight sub-activities leading to either GHG emissions and CO_2 sequestration (**Table 2**). In terms of GHG emissions, this report accounts for only CO_2.

Table 2: NH activities leading to CO_2 emissions, CO_2 sequestration and CO_2 emission avoidance in NH construction and maintenance

Phase of NH		Activity related to National Highways Considered	CO_2 emission/ sequestration/avoidance
A	NH Construction	1. Embedded emissions in construction material used	Emission
		2. Transportation of Construction material	Emission
		3. Operation of Construction Equipment	Emission
		4. Biomass loss due to loss of forest areas & Felling of trees outside forests	Emission
B	Plantation	5. Avenue plantation	Sequestration
		6. Compensatory Afforestation	Sequestration
C	NH Operations & Maintenance	7. Traffic operations on the new/ upgraded National Highway stretches	Avoided
		8. NH maintenance	Emission

For quantifying CO_2 emitted, CO_2 avoided and CO_2 sequestered, relevant activity data have been collated from the Environment Impact Assessment reports (EIAs), Detail Project Reports (DPRs) and other Project Design Documents (PDDs) of each of the NH stretch considered. Operation data in terms of toll data and maintenance data for some stretches also has been sourced from NHAI data base. The methodology of estimation and the results are described in Chapter 3, followed by the Conclusion in Chapter 4 and the Way Forward in Chapter 5.



3.0 METHODOLOGY AND RESULTS

3.1 Road Construction and Maintenance

3.1.1 Methodology

This section highlights the methods available for estimating carbon footprint as well as the methodology adopted by TERI for the calculation of carbon emissions during the construction and maintenance phases of NH.

Methods available for estimating GHG emissions from NH construction and maintenance include:

1. **Environmental Input-Output (EIO):** It uses a top-down approach to account for resource flows and environmental impacts based on input-output tables. Generic data at the National level is used to calculate GHG emissions at the industry level based on the emission intensity of respective industries. This method is used to model carbon footprint and provides a holistic view of the economic interdependence of industries, but it lacks process specificity.
2. **Life Cycle Analysis (LCA):** It is a process-based and uses a bottom-up 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).
3. **Hybrid IO-LCA:** 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.

This report adopts the LCA approach. The major reasons for the selection of the LCA approach to undertake this study are:

1. This approach complies with greenfield as well as brownfield projects. It is product/service-specific and thus is data intensive (Eskinder Demisse Gemechu,2009).
2. It systematically records and analyses the carbon emissions and carries out an integrated assessment throughout the entire life cycle of a product or service.
3. The LCA method has been widely accepted across the world to estimate the carbon footprint (CF) of infrastructure sectors, especially roads.
4. An end-to-end analysis of the product/service can be carried out considering all raw materials, transportation, production processes, and usage and disposal of the product.

The LCA framework used (TERI, 2012) is in line with the ISO 14000 framework and takes into account the international best practices for carrying out the LCA of road infrastructure. The LCA method has been adopted as it is the most widely used method to assess the environmental implications of products/services and product carbon footprint determination.

The MS excel-based tool estimates emissions for different representative projects/stretches, which generates highway-level emissions factors for different types of highways during the construction and maintenance phases. These emissions factors are then used to determine an estimate for the total CO_2 emissions for the selected sections of NH.

A similar excel-based approach has been adopted by the World Bank to estimate the life cycle emissions for the construction and maintenance phases of rail and road projects in the Democratic Republic of Congo.

Figure 1 highlights the phases and processes involved while calculating the CO_2 emissions of highways during construction and maintenance phases.

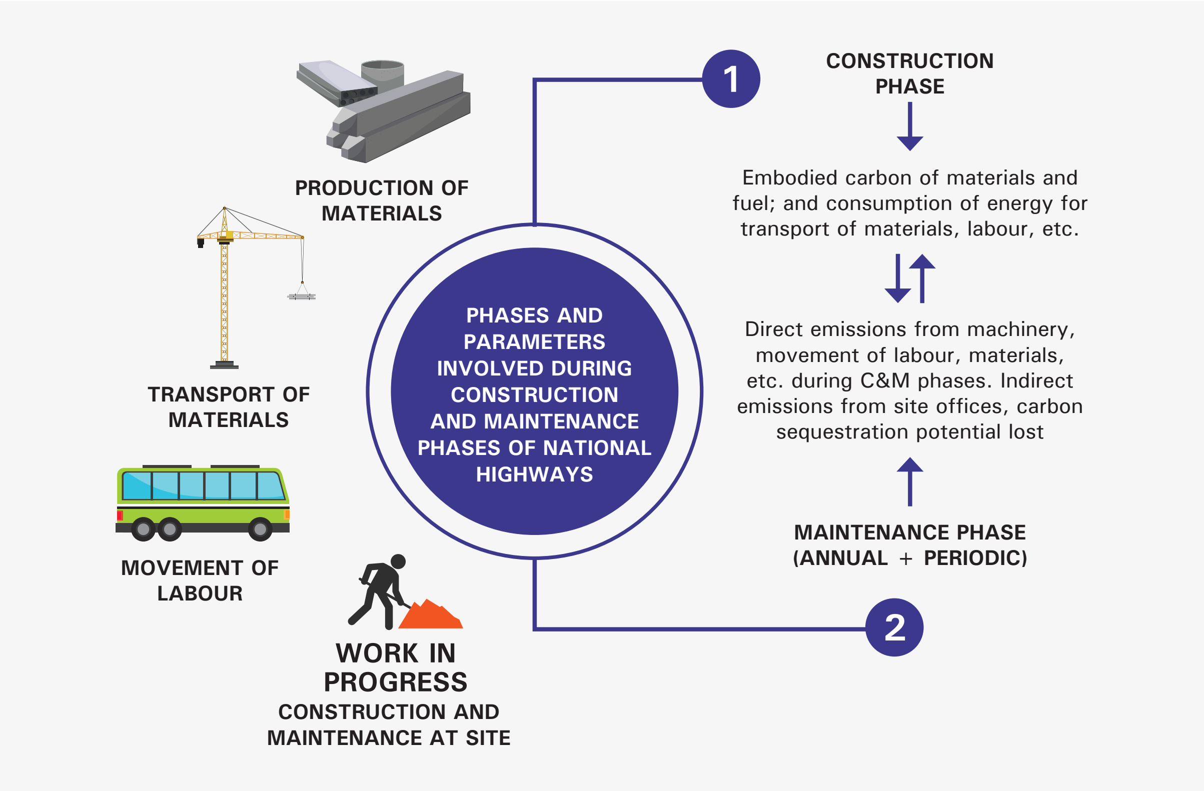


Figure 1: Phases and processes involved while calculating CO_2 emissions due to construction and maintenance of highways; Source: TERI

Table 3 highlights the parameters that need to be considered for estimating CO_2 emissions from construction and maintenance of NH. It also indicates the parameters that have not been included in the present calculations and the rationale thereof.

Table 3: Scope of LCA/CF framework for estimating project level/stretch-wise CO_2 emissions

Carbon Sources	Included	Remarks/Sources
Construction Phase		
Production of construction materials		
Embodied energy and CO_2 of construction material	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	The 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 MoEFCC (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 MoEFCC (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	Considered in section 3.4	It is assumed that compensatory vegetation will be planted to make up for the carbon sequestration potential lost.
Maintenance Phase		
Activities associated: - Annual and periodic maintenance works. - Material consumption (embodied energy and CO_2) - Energy use on-site	 Y Y Y	India-specific coefficients from AEI (2009) International values from Hammond and Jones (2008) India-specific CO_2 emission factors used from MoEFCC (2010) and ARAI (2007)

Source: TERI

Various parameters considered during the construction phase include material and fuel usage, movement of fuel and material, movement of labour, etc. For the maintenance phase, periodic and annual maintenance have been considered to estimate the total CO_2 emissions in tonnes of CO_2.

The following equations is used for estimating CO_2 emissions during the construction and maintenance phases:

Total CO_2 emissions = Material Usage + Fuel Usage + Transport of Materials, Labour, Fuel, etc.

= [Quantity of material (kg) * Embodied Carbon (kg of CO_2/kg of material)] + [Quantity of fuel used (litre) * Embodied Carbon (kg of CO_2/ litre of fuel)] + ({[No of trips * lead distance (km)]/ fuel efficiency (km/litre) *2} + {idling time (hour) * no of trips * idling efficiency (litre/hour) *2} * Density of fuel (kg/litre) * Embodied Carbon (kg of CO_2/kg of fuel))

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Assumptions while calculating CO_2 emissions during construction and maintenance phases are as follows:

- 100 km lead distance assumed for construction materials
- Construction materials are carried by 25-tonne vehicle with 4.42 kmpl fuel efficiency (Diesel)
- Density of compacted GSB: 2200 kg/m^3, Base: 2200 kg/m^3, Bituminous and concrete layer: 2400 kg/m^3
- 350 kg of cement for one cubic meter of concrete (PQC)
- For fuel consumption, the following factors have been considered:
  - » On-site electricity consumption
  - » Diesel consumption (generators, machinery and vehicles)
  - » Petrol consumption (vehicles & machinery, if any)
  - » Others, including the consumption of kerosene, LPG, natural gas and biomass at the site

3.1.2 CO_2 emissions from road construction and maintenance

The total CO_2 emissions from the construction phase range from 16,880 tCO_2 to 30,37,371 tCO_2. Similarly, for the maintenance phases, CO_2 emissions range from 33,430 tCO_2 to 6,52,349 tCO_2. Notable, the accuracy of the result is dependent on the input parameters, namely the quantity of materials consumed, fuel consumption at the site, and energy consumption for the movement of materials, staff/labour, etc. As seen in **Table 4**, the values for construction and maintenance of per lane km of NH vary across stretches as information provided by NHAI is limited in nature.

Table 4: CO_2 Emissions during Construction and Maintenance Phases

S. No.	NH Section	Length considered for construction and maintenance phases (km)	No. of Lanes	Total CO_2 emissions during Maintenance (tonnes of CO_2)	Total CO_2 emissions (tonnes of CO_2) Maintenance Phase
	Greenfield				
1	Eastern Peripheral Expressway (EPE) NE-2	136	6	30,37,371	6,52,349
2	Ahmedabad-Vadodara Expressway (NE-1)	93.3	6	NE	33,430
3	Ismailabad-Narnual Section (Trans Haryana) NH-152D	227	6	2,61,295	NE
4	Delhi-Meerut Expressway (NE-3)	82	6/8	2,08,122	72,656
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	2/4	42,962	NE
	Brownfield				
6	Delhi-Agra Section (NH-2)	179.5	6	78,518	47,445
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	4	57,427	42,077
8	Panipat-Jalandhar Section (NH-44)	291.1	6	3,25,904	2,09,970
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	93.54	4	1,89,735	NE
10	Yedeshi-Aurangabad Section (NH-52)	189	4	99,254	39,873
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	4	1,12,963	66,884
12	Pune Solapur Highway (Yavat-Temburni Section) NH-65	104.4	4	45,794	NE
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114	4	99,431	NE
14	Guwahati to Nagaon Highway (Khanapara - Dharamtul Section) NH-27	66.6	4	1,83,464	NE
15	Walayar (KL/TN border)-Edapally Section (NH-544)	121.49	4/6	70,401	NE
16	Porbandar-Dwarka Section (NH-51)	117.7	4	4,20,578	NE
17	Pasighat-Bomjur, Arunachal Pradesh (NH-13)	22.2	2	51,167	NE
18	Pasighat-Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.4	2	3,78,186	NE
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	6	16,880	NE
20	Banihal Jammu Highway (Quazigund-Banihal Section) NH-1A	16.26	4	37,207	NE

NE: Not estimated; Note: Due to limited availability of data, CO_2 emissions for some of the stretches could not been estimated; Source: TERI

3.2 NH Traffic Operations

In case of estimation of fuel consumption by different vehicles during traffic operation, the following assumptions have been made:

- The vehicle types considered are: Cars- Small, Cars-Big, Motorized Two Wheelers (MTW), Auto, Bus, Light Commercial Vehicles (LCV), Heavy 2/3 Axle Commercial Vehicles (HCV) and Multi-Axle Commercial Vehicles (MCV)
- Road types mainly considered are: Single Lane, Two Lane, Four Lane Divided, Six Lane Divided and Eight Lane Divided
- The Passenger Car Units (PCU) for different vehicle types are considered from IRC guidelines (IRC 64, 1990 and IRC 106, 1990).[4]
- As fuel consumption equations are not available for CNG vehicles and also CNG vehicular traffic is insignificant on highways (about 2-3%), hence not considered in this fuel consumption estimations separately.
- Average values of road quality data (roughness, rise and fall etc.) from the entire section have been considered wherever individual sections data is not available.
- Toll data has been considered wherever it is available, but the peak hour phenomenon could not be observed in toll data because of the discharge at toll booths depend on service time which is almost constant.
- All limitations with respect to toll data are applicable, especially the no-inclusion of local traffic.
- As realistic hourly traffic data was not available, so no. of congested hours prevailing on the sections have been considered appropriately for estimation of Congestion Factors.
- V/C (Volume - Capacity) Ratio appropriately considered from Peak hour factor of 10%
- Classified traffic volume considered in all the analyses is provided by NHAI from available DPR reports. All limitations of those DPRs are applicable to this study.
- Generated traffic (route shift and induced traffic) is not explicitly considered.

3.2.1 Methodology

The methodology adopted for estimating the fuel consumption from traffic operations has been presented in **Figure 2**. Majorly, the equations and method of estimation for speed, congestion factors and fuel consumption have been considered from IRC guidelines.[5] As per the equations and procedure given in these guidelines, the average speed has been estimated using road characteristics (road width, roughness, rise & fall, etc.) and also vehicular characteristics as per IRC Guidelines (IRC SP 30, 2019) for different vehicle types.

[4] IRC:106-1990. Guidelines for Capacity of Urban Roads in Plain Areas. The Indian Roads Congress (IRC), New Delhi, 1990. IRC:64-1990. Guidelines for Capacity of Roads in Rural Areas. The Indian Roads Congress (IRC), New Delhi, 1990.

[5] IRC: SP:30-2019. Manual on Economic Evaluation of Highway Projects in India. The Indian Roads Congress (IRC), New Delhi, 2019.

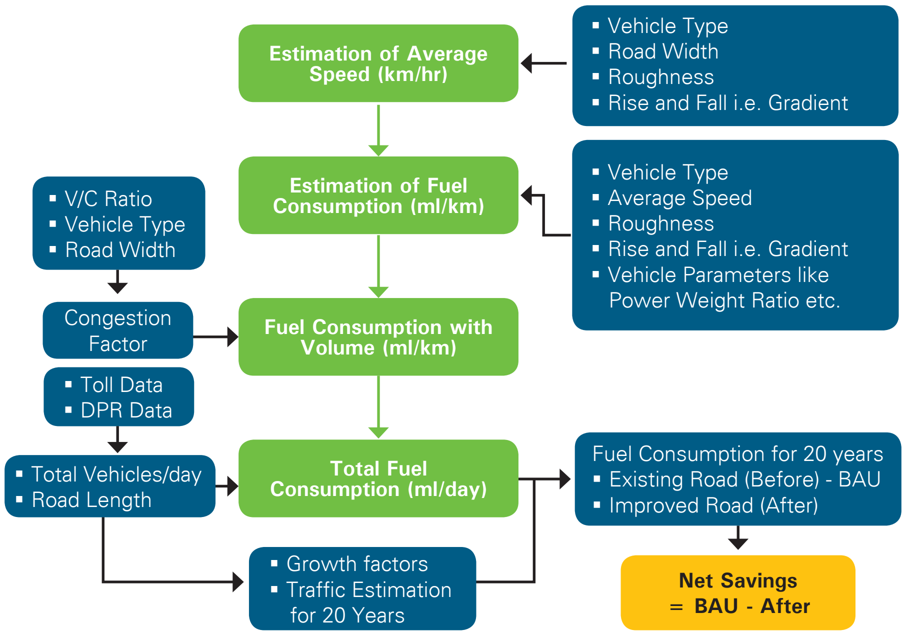


Figure 2: Adapted methodology for estimation of fuel consumption during traffic operations on national highways; Source: CSIR-Central Road Research Institute (CRRI)

Utilizing the estimated speed, fuel consumption has been estimated from the fuel consumption equations using IRC Guidelines (IRC SP 30,2019) for different vehicle types. Based on prevailing traffic volume, V/C ratios are being calculated, and congestion factors are being arrived from the congestion factor equations given in IRC SP 30 (2019). Using these factors, fuel consumption for prevailing traffic conditions has been estimated for different vehicle types. Considering the total traffic volume and road length, the total fuel consumption has been estimated for a day.

These estimations have been made for alternate scenarios i.e. BAU and improved conditions (namely widening). Accordingly, the net savings have been estimated from these. The total framework is described in Equations (2) to (5).

$$v_i^k = f(W^k, RG^k, RS^k, FL^k)_i \qquad \text{-------- (2)}$$

$$FC_i^k = f(v_i^k, RG^k, RS^k, FL^k, PWR_i) \qquad \text{-------- (3)}$$

$$CF_i^k = f(V^k, C^k, \frac{v^k}{c})_i \qquad \text{-------- (4)}$$

$$FC^k = L^k * \sum_{i=1}^{n} CF_i^k * Q_i * FC_i^k \ (4). \qquad \text{-------- (5)}$$

Where

v_i^k is average speed (km/hr) for vehicle type 'i' on road type 'k'

W^k is Road Width (m) for Road type 'k'

RG^k is Roughness (mm/km) for Road type 'k'

RS^k is Rise (m/km) for Road type 'k'

FL^k is Fall (m/km) for Road type 'k'

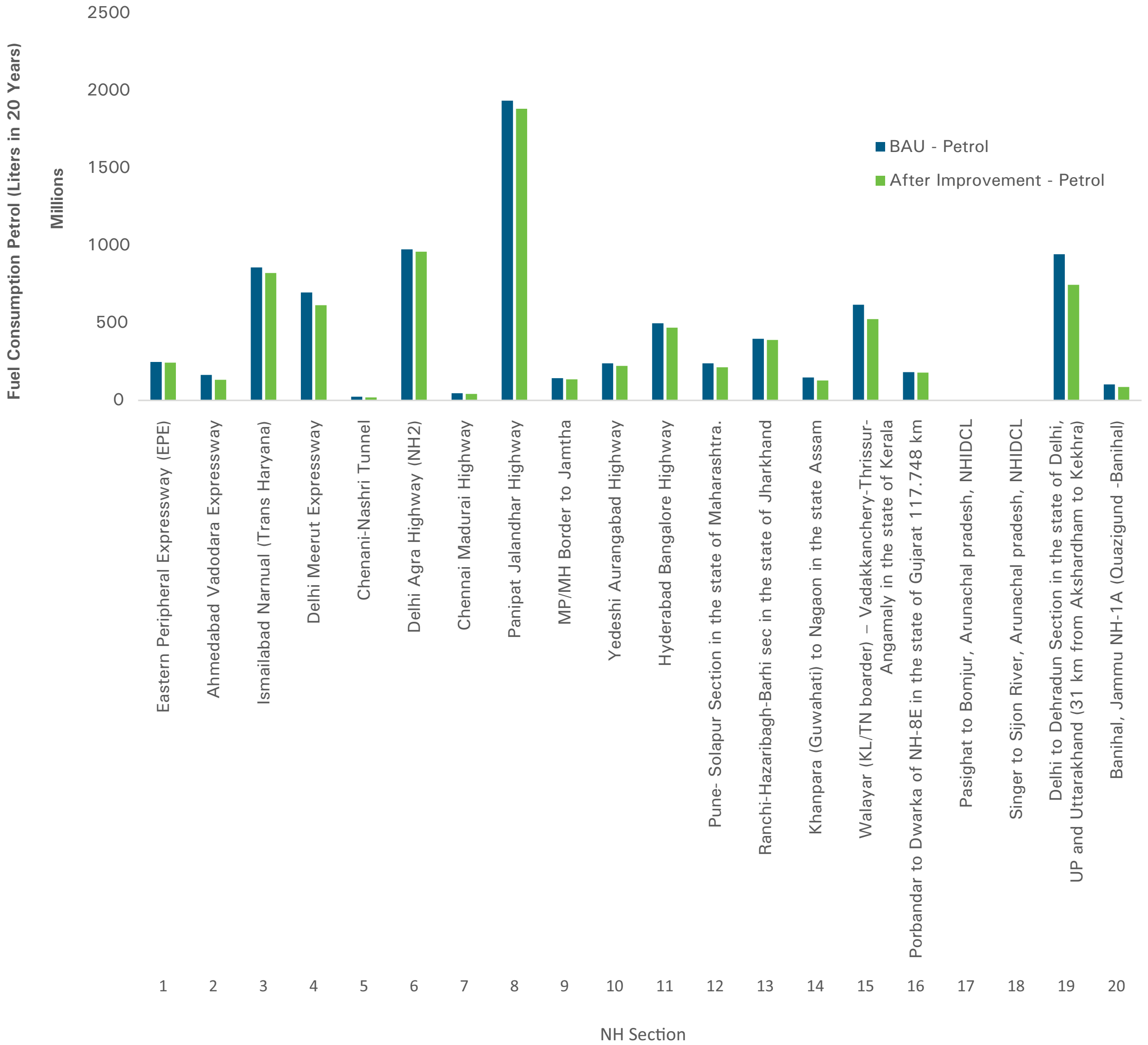
FC_i^k Fuel Consumption (ml/km) for vehicle type 'i' on road type 'k'

PWR_i Power Weight Ratio for vehicle type 'i'
CF_i^k Congestion Factor for vehicle type 'i' on road type 'k'
V^k Peak Hour Traffic Volume (PCU/hr) on road type 'k'
C^k Roadway Capacity (PCU/hr) on road type 'k'
$\frac{V}{C}^k$ Volume - Capacity Ratio for road type 'k'
FC^k Total Fuel Consumption (ml) on road type 'k'
L^k Length of Road (km) of road type 'k'
Q_i Traffic Volume (Veh/day) for the vehicle type 'i'

3.2.2 Fuel consumption estimation due to traffic operations

As discussed in the previous sections, a total of 20 nos. of NH sections have been considered for the estimation of fuel consumption. Utilizing the above methodology with assumptions, the results in terms of fuel consumption have been estimated for a 20-year period in the cases of Business As Usual (BAU), and Improvement and results are shown in Figure 3 (a) and (b) for petrol and diesel, respectively. From these results, it can be inferred that the estimated total fuel consumption from 20 nos. of sections for the BAU scenario is about 50.96 Billion litres (in 20 years) which have a 17% share of Petrol and 83% share of Diesel. In the case of the Improvement scenario, it can be inferred that the estimated total fuel consumption is about 41.16 Billion litres (in 20 years) which has a 19% share of Petrol and 81% share of Diesel. It can also be inferred from the results, a total of about 19% of reduction in fuel consumption have been observed compared to the BAU case. The details of these estimations with respect to vehicle wise given in Appendix A. The share of different vehicle types is presented in Figure 4 for both BAU and Improvement Cases. From Figure 4, it can be seen that more than 50% share of fuel consumption is from HCV and MCV. Accordingly, fuel saved from the improvement of NH is calculated and shown in Figure 5, and the share of different vehicle types in fuel savings is shown in Figure 6. It can be seen from Figure 6 that major fuel consumption (savings) has been observed from the vehicle types of MCV and HCV, i.e. 53% and 23%, respectively.

a. Fuel Consumption (Petrol)



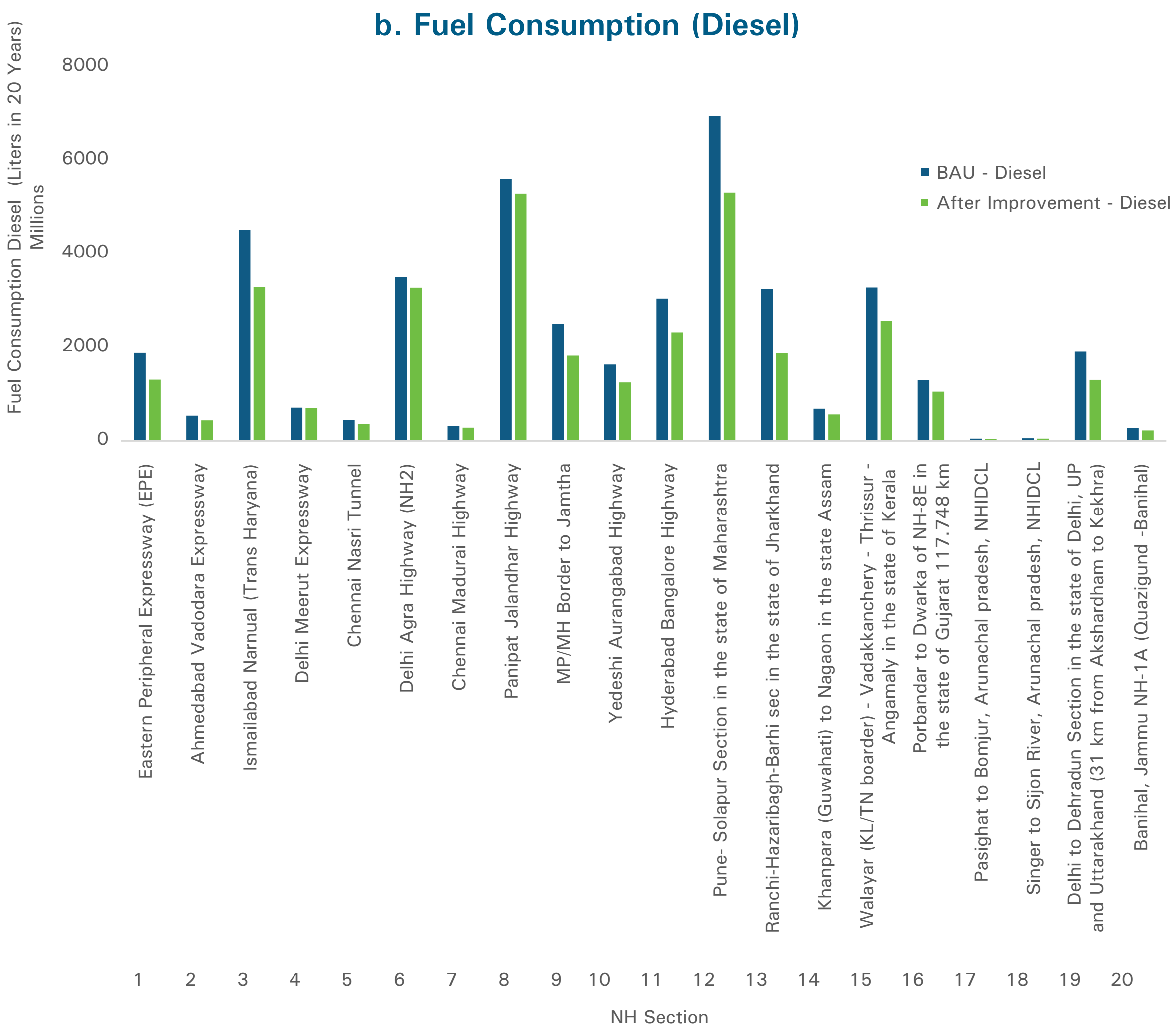
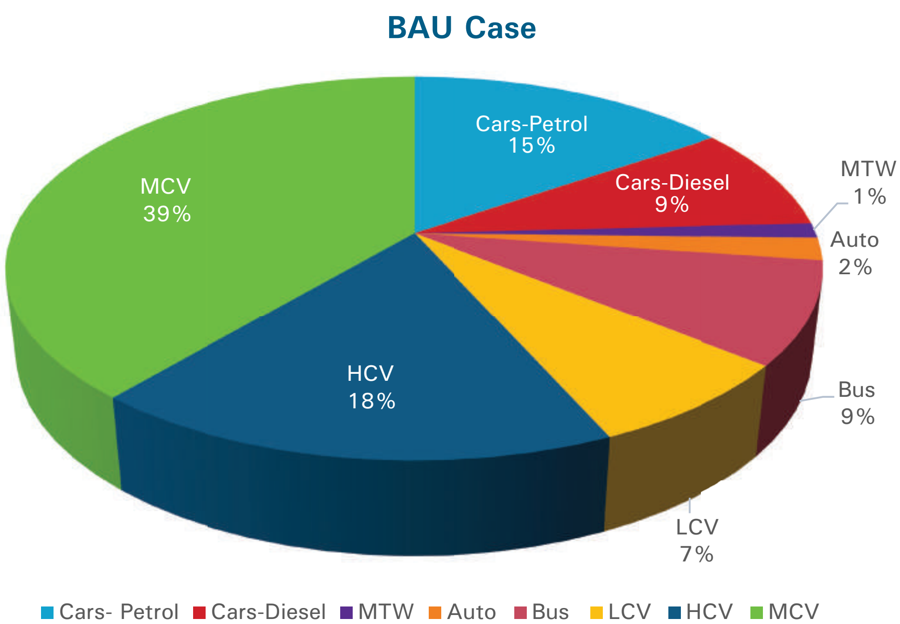


Figure 3: Estimated fuel consumption on different NH sections for BAU and Improvement Case
Source: CRRI



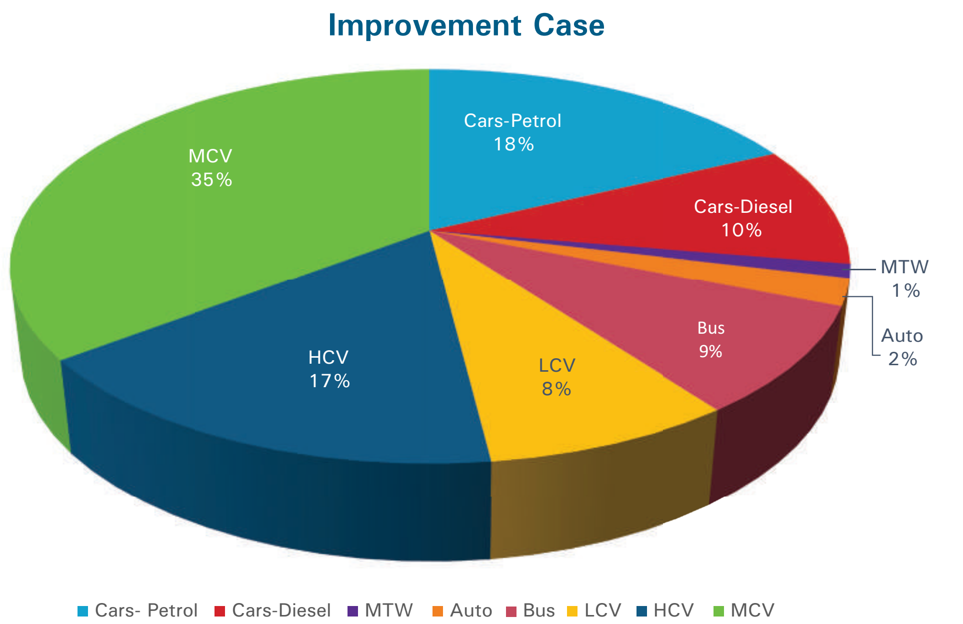


Figure 4: Share of fuel consumption of different vehicles types for BAU and Improvement Cases

Source: CRRI

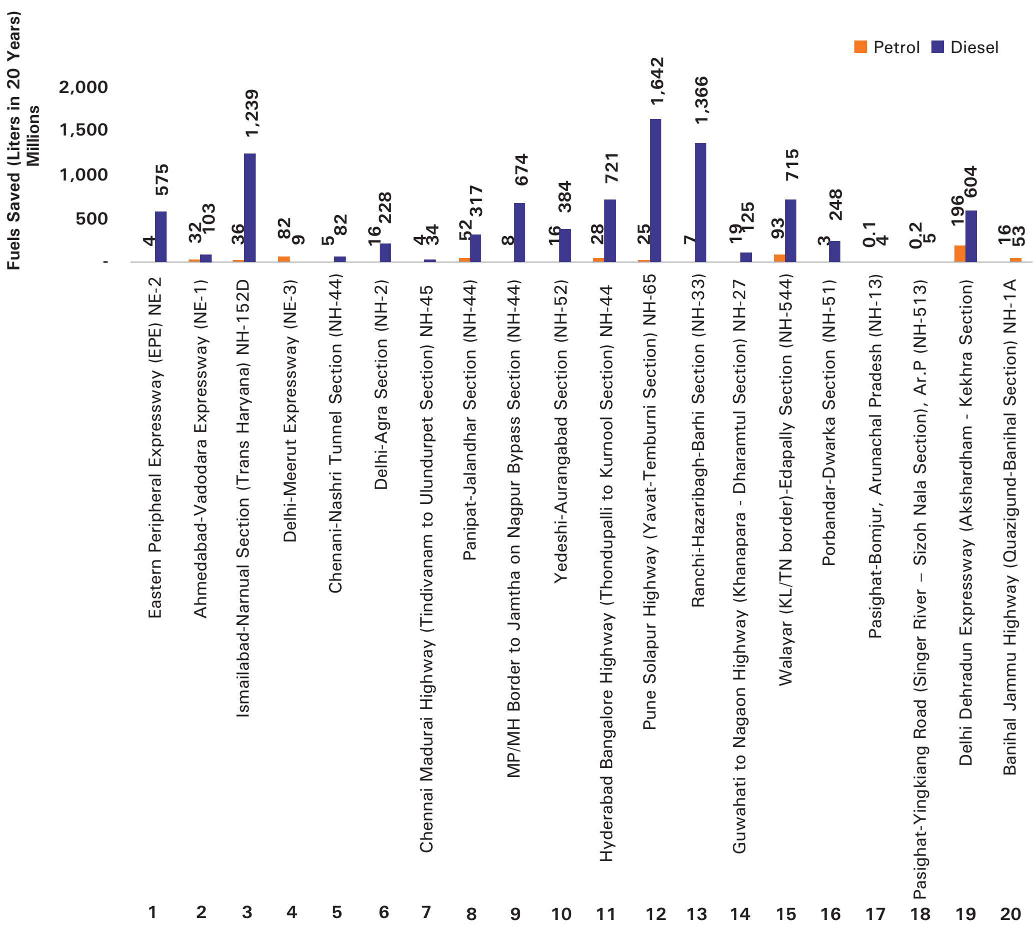


Figure 5: Estimated Fuel savings on different NH sections after improvement

Source: CRRI

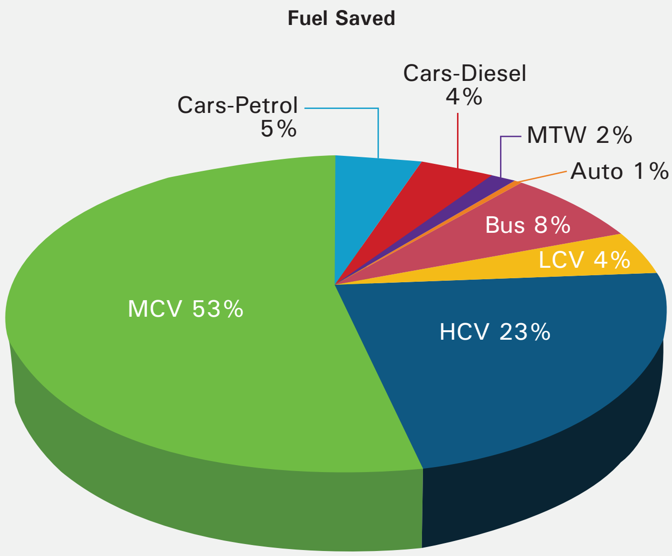


Figure 6: Share of fuel savings of different vehicle types after improvement

The estimated fuel consumption savings in 20 years for the selected NH sections are shown in **Table 5**. From Table 5, it can be seen that the estimated avoided fuel consumption is about 9.77 billion litres in 20 years, which have a share of 7% Petrol and 93% Diesel. The savings in petrol range from -2% to 21%, and in the case of Diesel, it ranges from 1% to 42% for the identified 20 nos. of NH sections. The overall savings are in the range of 19% in terms of total fuel consumption for 20 years.

Table 5: Fuel saved and avoided CO_2 emissions on selected NH stretches

S. No.	NH Section	Length (km)	Fuel Saved (Million Litres in 20 Years)		Fuel Saved (in %)	
			Petrol	Diesel	Petrol	Diesel
	Greenfield stretches					
1	Eastern Peripheral Expressway (EPE) NE-2	136.0	3.78	575.06	2%	30%
2	Ahmedabad - Vadodara Expressway (NE-1)	93.3	32.03	103.33	19%	19%
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227.0	36.15	1,239.23	4%	27%
4	Delhi - Meerut Expressway (NE-3)	82.0	82.30	9.21	12%	1%
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	5.23	82.38	21%	19%
	Brownfield stretches					
6	Delhi - Agra Section (NH-2)	179.5	15.53	228.19	2%	7%
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	4.46	33.85	10%	11%

S. No.	NH Section	Length (km)	Fuel Saved (Million Litres in 20 Years)		Fuel Saved (in %)	
			Petrol	Diesel	Petrol	Diesel
8	Panipat - Jalandhar Section (NH-44)	291.1	52.05	316.67	3%	6%
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	7.93	673.93	6%	27%
10	Yedeshi - Aurangabad Section (NH-52)	189.0	16.40	384.27	7%	23%
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	28.47	720.66	6%	24%
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.4	25.41	1,641.84	11%	24%
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	6.62	1,365.64	2%	42%
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	19.30	125.05	13%	18%
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.6	93.18	714.85	15%	22%
16	Porbandar to Dwarka Section (NH-51)	117.7	2.89	248.19	2%	19%
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	0.14	3.59	4%	7%
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH -513)	23.4	0.19	5.25	5%	10%
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	196.08	604.33	21%	32%
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.5	16.46	53.26	16%	19%
	Total	**2,191.5**	**644.60**	**9,128.77**		

3.2.3 CO_2 emissions avoided

The estimated quantity of fuel saved/avoided, i.e. petrol and diesel due to new construction (Greenfield Alignment) and widening (Brownfield alignment) of NH projects have been converted into CO_2 based IPCC emission factorising fuel emissions by u (IPCC, 1996 and IPCC, 2006)[6].

Further, CO_2 (in terms of kg or tonne) for 20 years period has been estimated by using the Net Calorific Value (NCV) of respective fuels (Petrol and diesel), which first converts the quantity of fuel saved /avoided into energy terms, which in turn is converted into CO_2 by using appropriate fuel-based emission factors (Singh et al., 2008).[7] The calculation steps are given in Equation (6).

$$Co_2\ \text{Emissions(kg)} = \Sigma\alpha[\text{Fuel Energy(TJ)}\alpha \ {*}\text{Emission Factor}\ (\tfrac{kg}{TJ})_\alpha] \qquad \text{.................6}$$

[6] IPCC, 1996. Revised guidelines for national greenhouse gas inventories, Intergovernmental Panel on Climate Change (IPCC), Volume 2 Energy. IPCC, 2006. Guidelines for national greenhouse gas inventories, Intergovernmental Panel on Climate Change (IPCC), Workbook Volume 2

[7] Singh, A. Gangopadhyay, S. Nanda, P. K., Bhattacharya, C., Sharma, C. and Bhan, C. (2008). Trends of greenhouse gas emission from the road transport sector in India, Science of total the environment 390(1), 124-131.

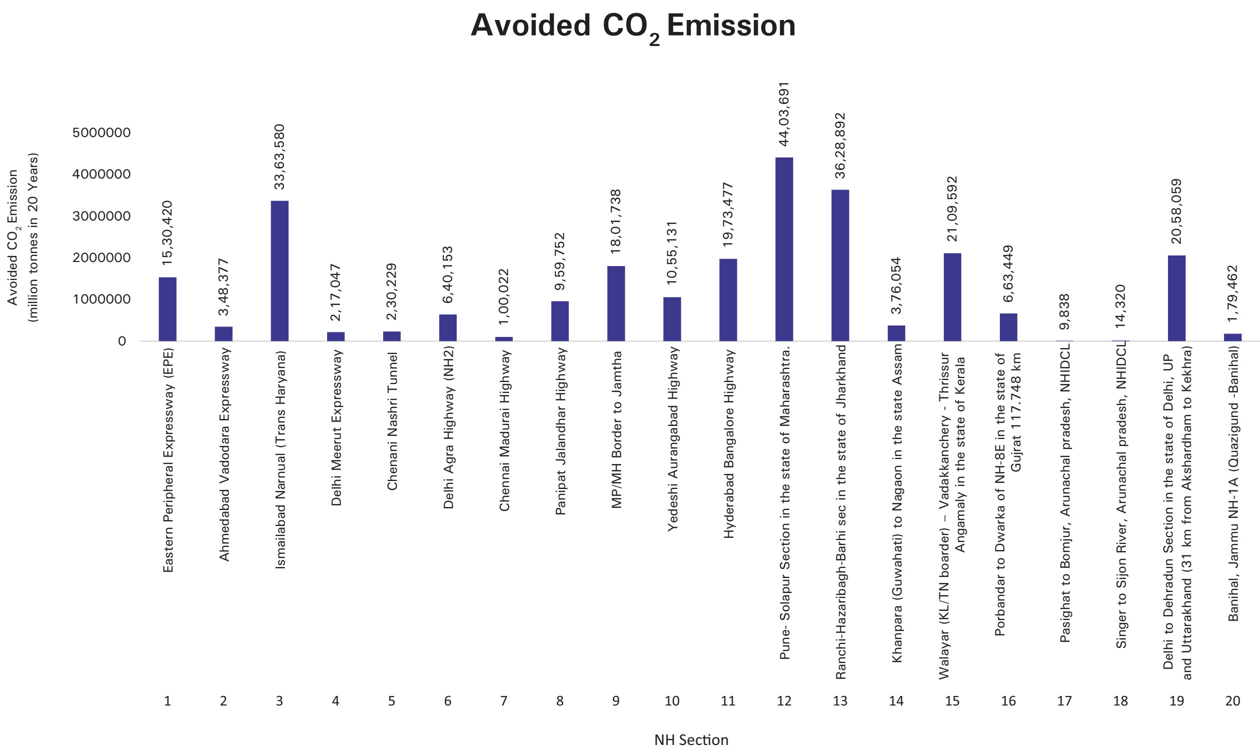


Figure 7: Estimated avoided CO_2 emissions on different NH sections due to improvement; **Source:** CSIR - IIP

Table 6: CO_2 emissions saved in selected NH stretches

S. No.	NH Section	Length (km)	CO_2 Emission Saved (Tonnes) - 20 Years	CO_2 Emission Saved (Tonnes per km) - 20 Years
	Green Field			
1	Eastern Peripheral Expressway (EPE) NE-2	136.0	15,03,998.52	11,058.81
2	Ahmedabad - Vadodara Expressway (NE-1)	93.3	3,40,579.28	3,650.29
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227.0	33,03,917.85	14,553.42
4	Delhi - Meerut Expressway (NE-3)	82.0	2,08,622.11	2,544.17
5	Chenani - Nashri Tunnel Section (NH-44)	10.8	2,25,987.14	20,924.74
	Brown Field			
6	Delhi - Agra Section (NH-2)	179.5	6,28,303.49	3,500.30
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	98,054.09	1,345.05
8	Panipat - Jalandhar Section (NH-44)	291.1	9,40,339.88	3,230.30
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	17,70,433.25	18,655.78
10	Yedeshi - Aurangabad Section (NH-52)	189.0	10,36,126.27	5,481.48
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	19,38,056.29	10,288.67

S. No.	NH Section	Length (km)	CO_2 Emission Saved (Tonnes) - 20 Years	CO_2 Emission Saved (Tonnes per km) - 20 Years
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.4	43,26,834.37	41,444.77
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	35,66,376.17	31,284.00
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	3,68,510.91	5,532.78
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.6	20,68,138.90	16,592.90
16	Porbandar to Dwarka Section (NH-51)	117.7	6,51,923.85	5,536.60
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	9,661.73	436.20
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.4	14,064.49	601.64
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	20,11,601.87	64,474.42
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.5	1,75,447.16	7,807.71
	Total	**2,191.5**	**2,51,86,977.61**	**11,493.03**

Source: CSIR - IIP

3.3 Carbon Loss due to Loss of Green Cover

3.3.1 Methodology

Green cover here refers to forest area and trees outside forests (ToF). The biomass lost due to felling of ToF and clearance of forests that pave the way for construction of National Highways in most cases, lead to CO_2 emissions. The biomass pools can be divided into Above Ground Biomass (AGB), Below Ground Biomass (BGB), and Soil Organic Carbon (SOC). Deadwood and litter also form part of the biomass pool. Equation 7 below depicts the methodology used for estimating CO_2 emissions from loss of biomass due to removal of forests and felling of ToF. Note that the deadwood and litter biomass pool has not been considered as they constitute less than 1% of the total C stock as indicated in the C reports of the FSI (FSI, 2012[8]; 2020[9]).

CO_2 emitted due to loss of green cover is expressed as:

CO_2 emitted from loss of green cover =

$$\Sigma^{20}_{i=1}\{[(\text{C per ha in AGB}) + (\text{C per ha BGB}) + (\text{C per ha in SOC})] \times [\text{total forest area loss} + \text{total equivalent area of TOF felled}]\} \times 44/12 \quad \text{.........(7)}$$

[8] FSI, 2012. Carbon stock in Indian forests. Published by Forest Survey of India, MoEFCC, GoI. Accessed last on Sept 8. 2022 from https://fsi.nic.in/carbon_stock/cover.pdf

[9] FSI, 2020. Trees Outside Forest Resources in India. FSI TECHNICAL INFORMATION SERIES Volume 2 No. 1 2020. Accessed last om 120922 from http://webline.co.in/fsi-result/technical-information-series-vol2-no1-2020.pdf

Here *i* indicates the stretches of NH

AGB: Above Ground Biomass

BGB: Below Ground Biomass

SOC: Soil Organic Carbon and

44/12 is the CO_2-C ratio for converting C to CO_2

3.3.2 CO_2 emissions due to loss of forest area and felling of trees outside forests

The basic data required pertaining to loss in forest area and TOFs felled is sourced from the EIAs and DPRs of NIAH for the corresponding projects. The number of ToFs felled have been also converted to area cleared. For all the 20 stretches considered in the present assessment, total area of forest loss amounted to 2179.40 ha or 2.18 thousand ha and total equivalent area of TOF felled was around 32698.90 ha or 32.70 thousand ha. Using equation 1, and taking per ha values of C stock in AGB, BGB and SOC of ToF and forests from FSI's Carbon reports, the total Carbon loss is 1st calculated of the it is estimated which is then converted to CO_2 using the CO_2-C ratio. CO_2 emission estimated as a result of total biomass loss across these 20 stretches is 652600.98 tons or 652.60 thousand tCO_2. Table 7 details the area lost, and corresponding C and CO2 emitted due to the felling of ToF and loss in forest areas.

Table 7: CO_2 emitted due to loss of forest area and felling of trees outside forests

S. No.	NH Section	Stretch Length (km)	Forest Area loss (ha)	ToF area felled (ha)	Carbon Loss in AGB	Carbon Loss in BGB (tonnes)	Carbon Loss in SOC (tonnes)	Total CO_2 Loss (tonnes)
Greenfield								
1	Eastern Peripheral Expressway (EPE) NE-2	136	6	4,404	252	29	788	3,925
2	Ahmedabad-Vadodara Expressway (NE-1)	93	NO	NO	NE	NE	NE	NE
3	Ismailabad-Narnual Section (Trans Haryana) NH-152D	227	59	82	833	230	4,438	20,187
4	Delhi-Meerut Expressway (NE-3)	82	52	12,188	1,709	589	7,948	29,168
5	Chenani-Nashri Tunnel Section (NH-44)	11	65	NO	1,932	488	3,027	5,446
Brownfield								
6	Delhi-Agra Section (NH-2)	180	140	177	3,805	1,494	9,316	14,616
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	73	ND	ND	NE	NE	NE	NE

S. No.	NH Section	Stretch Length (km)	Forest Area loss (ha)	ToF area felled (ha)	Carbon Loss in AGB	Carbon Loss in BGB (tonnes)	Carbon Loss in SOC (tonnes)	Total CO_2 Loss (tonnes)
8	Panipat-Jalandhar Section (NH-44)	291	1,163	ND	14,648	4,567	1,13,413	4,86,744
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	95	ND	ND	ND	NE	NE	NE
10	Yedeshi-Aurangabad Section (NH-52)	189	2	12,648	1,136	454	4,468	22,233
11	Hyderabad Bengaluru Highway (Thondupalli to Kurnool Section) NH-44	188	ND	3,000	631	248	635	5,557
12	Pune Solapur Highway (Yavat-Temburni Section) NH-65	104	22	31	667	267	2,574	3,507
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114	184	36	2,896	1,137	5,503	9,537
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	67	32	10	592	232	1,080	1,904
15	Walayar (KL/TN border)-Edapally Section (NH-544)	125	107	7	5,954	2,060	8,660	16,674
16	Porbandar-Dwarka Section (NH-51)	118	266	ND	3,793	1,489	14,047	19,330
17	Pasighat-Bomjur, Arunachal Pradesh (NH-13)	22	45	ND	1,588	327	4,459	6,374
18	Pasighat-Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23	8	ND	292	60	820	1,172
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31	11	ND	152	60	453	665
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	23	19	118	1,973	498	3,091	5,562
	Total	**2,192**	**2,179**	**32,699**	**42,855**	**14,229**	**1,84,719**	**6,52,601**

ND= No data, NO= Not Occurring, NE = Not estimated; Source: IORA

3.4 CO_2 Sequestration due to Avenue Plantations and Compensatory Afforestation

3.4.1 Methodology

Avenue plantations, median plantations and Compensatory Afforestation (CA) offer CO_2 sequestration opportunities to offset Carbon loss due to felling of trees and clearance of forests during NH construction. In India, such plantations are done as per the guidance of the Green National Highway Policy (2015).[9] Equation 8 presents the combination of parameters to estimate the total CO_2 that can be sequestered by avenue plantations and CA over a twenty year period. The period of sequestration chosen here is line with the default values adopted in the IPCC GPG guidelines (IPCC, 2003)[10] for stored carbon to reach its equilibrium. This period is also in line with the time period of economic analysis of highway projects. Data for the assessment is availed from EIAs and DPRs of the respective projects from NHAI.

$$\text{Total } CO_2 \text{ sequestered over a 20 year period} = \sum_{I=1}^{n} \{[(\text{C in AGB} + \text{C in BGB} + \text{SOC}) \times (44/12)] \times 20\} \quad \text{.......(8)}$$

Where

C in AGB = [Area under CA + equivalent area of AP & MP] in ha x tons of dm/ ha/ yr x CF of dm

C in BGB = tons of dry matter in AGB x R

SOC = C in (AGB+ BGB) x OCS

Here

AGB = Above Ground Biomass
BGB = Below Ground Biomass
CA= Compensatory Afforestation
AP = Avenue Plantation
MP= Median Plantation
SOC = Soil Organic Carbon
dm = dry matter
R = Ratio of BGB to AGB = 0.27
CF = Carbon Fraction of Dry matter = 0.47
OCS = Organic Carbon content of Soil =0.5
n = number of stretches

In compensatory afforestation, the User Agency is mandated to plant minimum 50 plants, or 10 times the no. of trees/plants felled whichever is more.[11] Information available for the National Highway stretches for Compensatory afforestation is the number of trees proposed to be planted/area to be planted and Net Present Value (NPV) of the diverted

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9 Green National Highway Policy, 2015. Published by the Ministry of Roads, Transport and Highways. Available at https://morth.nic.in/sites/default/files/Green_Highways_Policy.pdf

10 https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

11 MoEFCC, 2019. Handbook of guidelines for effective and transparent implementation of the provisions of Forest (Conservation) Act, 1980. Accessed on 11Sep, 2019 from https://parivesh.nic.in/writereaddata/FC/HANDBOOK_GUIDELINES/HANDBOOK_GUIDELINES18_03_2019.pdf

forest land. Wherever information on the number of trees planted was available, they have been converted to the equivalent area of plantation[8]. Additionally, if the data on NPV amount submitted for CA is available, it has been converted to the area in ha by considering per sapling cost of Rs 250/- and 1000 saplings per ha. This includes maintenance cost as well.

The estimates of annual C sequestration per ha in AGB, BGB and in soil assumes three scenarios of growth and mortality as depicted in Table 8.

Table 8: Scenarios applied to estimate CO_2 sequestration from avenue plantations and compensatory afforestation

	AGB Growth rates* t dm/ha/yr	Mortality rates
Best case scenario	13.5	Nil, 20%, 40%
Average case scenario	7.8	Nil, 20%, 40%
Low Case scenario	2.0	Nil, 20%, 40%

**Pertains to tropical and subtropical forest domain as available in 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

Source: IORA

3.4.2 CO_2 sequestration due to avenue plantation and compensatory afforestation

Based on expert judgement, three scenarios have been considered to capture the likely variability in the biomass growth and tree mortality rates. The three scenarios are presented in Table 9, and they are best case biomass growth scenario, average case biomass growth scenario and low case biomass growth scenario. The mortality rates considered are 0%, 20%, and 40%.

Using equation 8 and 9, it is estimated that cumulative CO_2 sequestration potential of the plantations (CA+avenue) in a 20-year period along all 20 stretches put together will be 804.30 thousand tonnes of CO_2, if the plantations grow at a maximum biomass growth rate of 13.5 t dm/ha/yr with no mortality registered. For the worse-case scenario if the plantations grow at the lowest biomass growth rate (2 tdm/ha/year) and highest mortality rate of 40%, they will sequester 419.25 thousand tons of CO_2 cumulatively within the same period. Whereas an average growth rate (7.8t dm/ha/yr) of biomass with an average mortality rate of 20% would potentially enable a sequestration of 584.27 thousand tons of CO_2 for all the stretches in the same 20 year period (See Table 9). Table 10 further details the CO_2 sequestration that can be achieved over a 20 year period by each of the 20 stretches of National Highways, if the plantations grow at an average growth rate of 7.8 t dm/yr.

Table 9: Potential CO_2 sequestration by Avenue plantation and Compensatory Afforestation for three biomass growth rate and mortality scenarios

Biomass Growth Rates	CO_2 sequestration (tCO_2)		
	0% mortality	20% mortality	40% mortality
Best case scenario with AGB growth rate of 13.5t dm/ha/yr	8,04,301.6	6,43,441.3	5,14,753
Average case scenario with AGB growth rate of 7.8 t dm/ha/yr	7,30,340.5	5,84,272.4	4,67,417.9
Low Case scenario with AGB growth rate of 2.0 t dm/ha/yr	6,55,081.7	5,24,065.4	4,19,252.3

Source: IORA

Table 10: Potential CO_2 sequestration by avenue plantations and Compensatory Afforestation over a period of 20 years for an average biomass growth rate scenario

S. No.	Stretches	Length (km)	No. of avenue trees planted (No.)	No. Of median trees/ bushes planted (No.)	Trees planted in CA (No.)	Cumulative area of Plantation (Ha)	CO_2 sequestered in 20 years with 0 mortality (tCO_2)	CO_2 sequestered with 20% mortality (tCO_2)	CO_2 sequestered with 40% mortality (tCO_2)
Greenfield									
1	Eastern Peripheral Expressway (EPE) NE-2	136	1,63,431	84,632	69,464	296	1,12,079	89,663	71,731
2	Ahmedabad - Vadodara Expressway (NE-1)	93.3	NO	NO	NO	NE	NE	NE	NE
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227	2,20,920	1,49,756	12,66,000	1,599	2,15,024	1,72,019	1,37,615
4	Delhi-Meerut Expressway (NE-3)	82.04	46,799	31,258	12,00,000	1,270	1,70,780	1,36,624	1,09,299
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	900	ND	ND	1	121	97	77
Brownfield									
6	Delhi-Agra Section (NH-2)	179.5	1,27,463	ND	ND	127	17,137	13,709	10,967
7	Chennai-Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	1,77,989	3,08,078	ND	409	55,025	44,020	35,216
8	Panipat-Jalandhar Section (NH-44)	291.1	50,000	1,50,000	ND	163	21,862	17,490	13,992
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	7,159	24,311	ND	25	3,416	2,733	2,186
10	Yedeshi-Aurangabad Section (NH-52)	189	1,03,102	1,03,867	1,03,867	285	38,310	30,648	24,518
11	Hyderabad-Bengaluru Highway (Thondupalli-Kurnool Section) NH-44	188.4	2,18,500	1,48,682	49,809	380	51,080	40,864	32,691
12	Pune Solapur Highway (Yavat-Temburni Section) NH-65	104.4	104	14,000	73,260	84	11,277	9,021	7,217

S. No.	Stretches	Length (km)	No. of avenue trees planted (No.)	No. Of median trees/ bushes planted (No.)	Trees planted in CA (No.)	Cumulative area of Plantation (Ha)	CO_2 sequestered in 20 years with 0 mortality (tCO_2)	CO_2 sequestered with 20% mortality (tCO_2)	CO_2 sequestered with 40% mortality (tCO_2)
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114	114	62,396	31,894	79	10,601	8,481	6,785
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	67	32,146	36,540	61	8,166	6,533	5,226
15	Walayar (KL/TN border)-Edapally Section (NH-544)	124.6	4,765	44,711	ND	38	5,154	4,123	3,298
16	Porbandar to Dwarka Section (NH-51)	117.7	68,122	ND	ND	68	9,159	7,327	5,862
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	ND	ND	ND	NE	NE	NE	NE
18	Pasighat-Yingkiang Road (Singer River-Sizoh Nala Section), Ar.P (NH-513)	23.4	ND	ND	ND	NE	NE	NE	NE
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	ND	ND	ND	NE	NE	NE	NE
20	Banihal Jammu Highway (Quazigund-Banihal Section) NH-1A	22.5	5,747	3,743	ND	9	1,150	920	736
	Total	**2,191.5**				**4,895**	**7,30,341**	**5,84,272**	**4,67,418**

Note: NO= Not Occurring, NE = Not Estimated, ND = No Data

Source: IORA

3.5 Net CO_2 Avoided from NH Construction and Operations

We have so far estimated CO_2 emission, CO_2 avoided, and CO_2 sequestration due to road construction, forest loss, tree felling, road operations, Road maintenance, avenue plantation, and compensatory afforestation, respectively. Adding up all this would lead us to assess net C avoided or emitted.

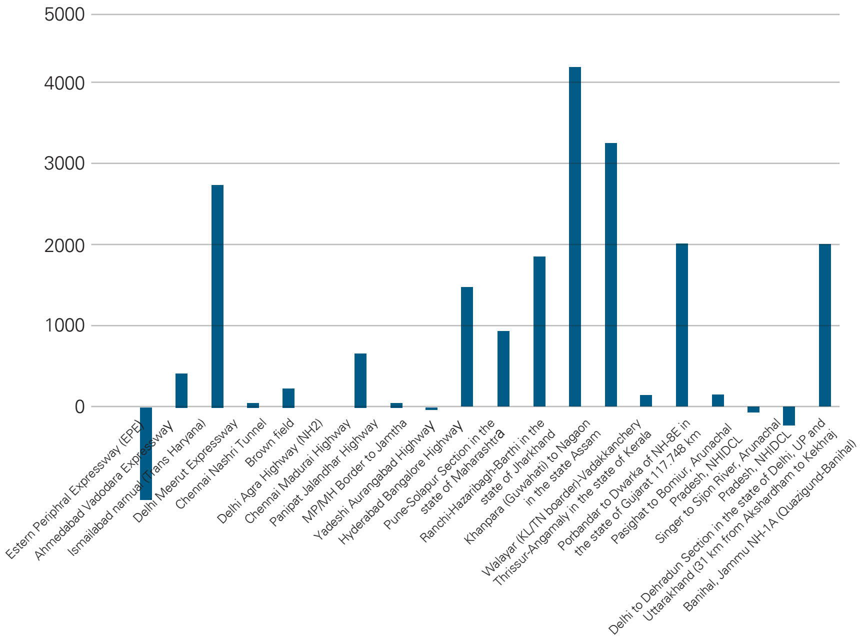
The following Equation (9) is applied to arrive at the net CO_2 avoided/emitted

$$\text{Net } CO_2 \text{ avoided or emitted in terms of } CO_2 = [(B+C) - (D+E+F)] \qquad \text{........(9)}$$

Where B, C, D, E and F are as follows:

B = Potential CO_2 saved over a 20-year period from NH operation
C = Potential CO_2 sequestered over a 20-year period in Avenue plantation and
D= CO_2 emitted due to Forest clearance and felling of trees outside forests
E = CO_2 emitted due to NH construction
F = CO_2 emitted due to NH maintenance

The estimates show that the C emissions can be avoided due to NH construction by avenue plantations and smoother NH operations with respect to business as usual (Table 11). The CO_2 sequestration vales considered here correspond to an average case growth rate of biomass and 20% mortality. In this assessment, the 20 stretches of NH together can potentially avoid 18236.62 thousand tons of CO_2. On a per km basis, the avoidance can be of the order of 8.32 thousand tons of CO_2. A stretch-by-stretch mapping of net C emissions avoided/emitted clearly indicates (Figure 8) that though the majority of the stretches are leading to net avoidance of C after their construction, but there are some stretches where net C emissions are still taking place.



Note: The +ve values represent net CO_2 avoidance, and -ve values indicate net CO_2 emission

Figure 8: Stretch by stretch estimated CO_2 avoided or emitted

Table 11: CO_2 avoided due to cumulative effect of NH construction, loss of ToF, forest area loss, NH operations and maintenance

		A	B	C	D	E	F	G=B+C-D-E-F
S. No	NH stretches	Length	CO_2 saved from NH operations along the entire stretch	CO_2 sequestered in Avenue plantation + CA	CO_2 emitted from Forest clearance & felling of TOF	CO_2 emitted due to NH construction & maintenance	CO_2 emitted during maintenance	Net CO_2 Emitted / Avoided*
		Km		tCO_2	tCO_2	tCO_2	tCO_2	tCO_2
	Green Field							
1	Eastern Peripheral Expressway (EPE) NE-2	136.00	1503998.16	89663.36	3925.24	3037371.00	652349.00	-2099983.72
2	Ahmedabad - Vadodara Expressway (NE-1)	93.30	340572.057	0	0	0.00	33430.00	307142.057
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227.00	3303626.34	172018.9	20187.16	261295.00	0.00	3194163.08
4	Delhi - Meerut Expressway (NE-3)	82.04	208723.707	136624.2	29167.79	208122.00	72656.00	35402.117
5	Chenani-Nashri Tunnel Section (NH-44)	10.80	225987.192	96.8	5446.17	42962.00	0.00	177675.822

		A	B	C	D	E	F	G=B+C-D-E-F
S. No	NH stretches	Length	CO_2 saved from NH operations along the entire stretch	CO_2 sequestered in Avenue plantation + CA	CO_2 emitted from Forest clearance & felling of TOF	CO_2 emitted due to NH construction & maintenance	CO_2 emitted during maintenance	Net CO_2 Emitted / Avoided*
		Km		tCO_2	tCO_2	tCO_2	tCO_2	tCO_2
	Brown field							
6	Delhi - Agra Section (NH-2)	179.50	628303.85	13709.35	14615.57	78518.00	47445.00	501434.63
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.90	98054.145	44020.21	0	57427.00	42077.00	42570.355
8	Panipat - Jalandhar Section (NH-44)	291.10	940340.33	17489.89	486743.51	325904.00	209970.00	-64787.29
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	1770433.25	2733.041	0	189735.00	0.00	1583431.291
10	Yedeshi - Aurangabad Section (NH-52)	189.00	1035999.72	30647.66	22233.26	99254.00	39873.00	905287.12
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.40	1938385.43	40863.81	5556.96	112963.00	66884.00	1793845.28
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.40	4326833.99	9021.213	3507.37	45794.00	0.00	4286553.833
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.00	3566376	8480.95	9537.14	99431.00	0.00	3465888.81
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.60	368483.148	6532.95	1904.01	183464.00	0.00	189648.088
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.60	2067475.34	4122.8	16674.23	70401.00	0.00	1984522.91
16	Porbandar to Dwarka Section (NH-51)	117.70	651657.82	7326.9	19329.71	420578.00	0.00	219077.01
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.20	9683.64	0	6373.58	51167.00	0.00	-47856.94
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.40	14078.376	0	1171.68	378186.00	0.00	-365279.304
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.20	2011601.9	0	665.19	16880.00	0.00	1994056.71
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.50	175673.475	920.36	5562.41	37207.00	0.00	133824.425
	Total	**2191.50**	**25186977.61**	**584272.40**	**652600.98**	**5716659.00**	**1164684.00**	**18236616.28**

Note: The +ve values represent net CO_2 avoidance, and -ve values indicate net CO_2 emission

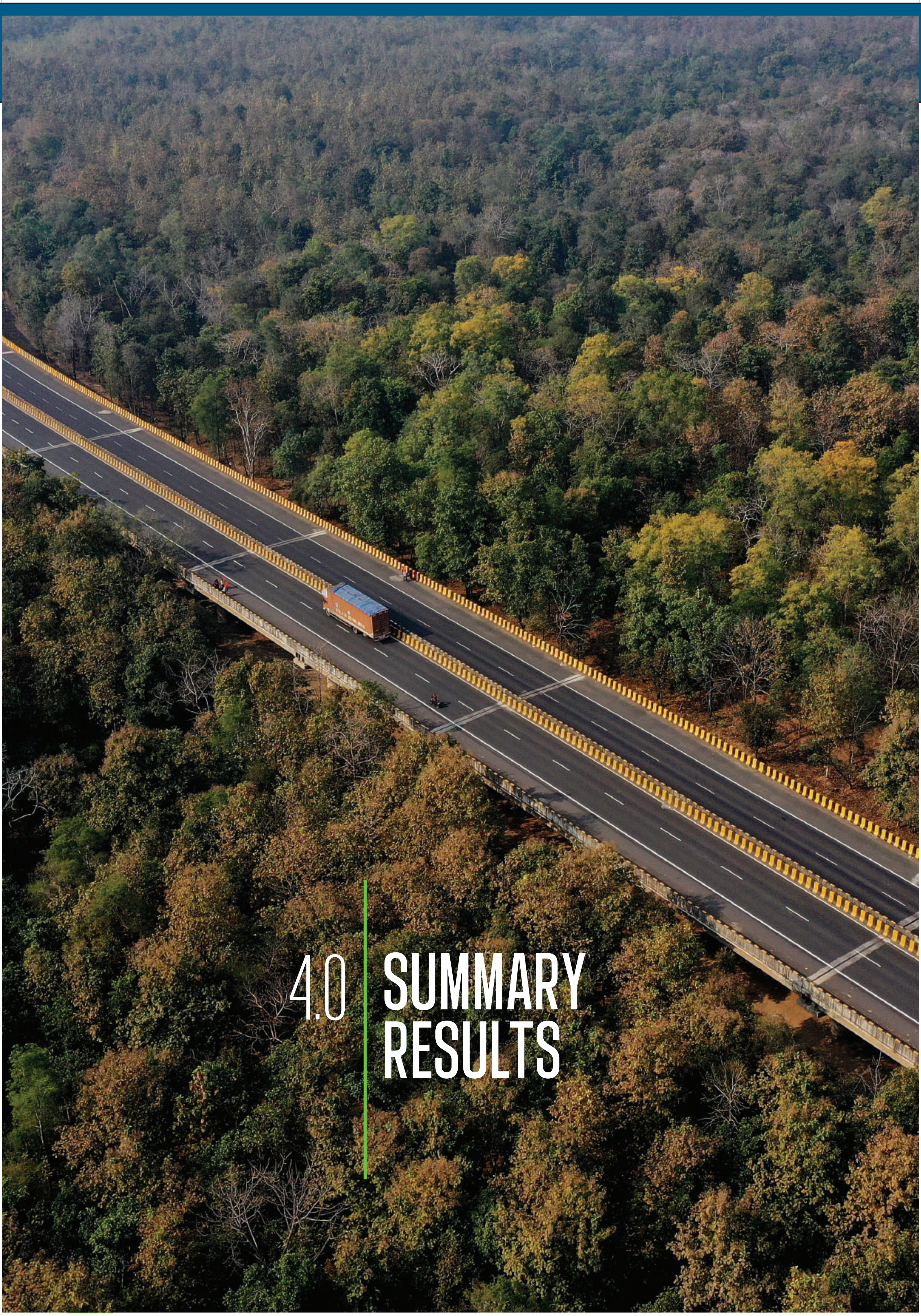
The length of NH constructed since 2014 till date is 776, 265 kms. Based on the CO_2 avoided per km value derived from the exercise carried out so far, it is estimated that the 77,265 kms of highways constructed till date since 2014 can potentially avoid 32.15 million tCO_2 annually and 642.95 million tCO_2 cumulatively in next 20 years. This is equivalent to CO_2 sequestration by 31,826 million trees. Table 12 presents year by CO_2 sequestration by each parcel of NH built annually.

Table 12: CO_2 emissions avoided by NH constructed since 2014 till date and equivalent number of trees

Year	NH Greenfield Construction as of Jan 2023*	NH Brownfield Construction as of Jan 2023*	Total NH Construction as of Jan 2023*	CO_2 avoided annually	CO_2 avoided in next 20 years	Equivalent no. of trees
	Km	Km	Km	tons	Tons	No.
2014-15	-	4,410	4,410	18,34,868.7	3,66,97,374	1,81,65,63,954
2015-16	-	6,061	6,061	25,21,800.27	5,04,36,005.4	2,49,66,42,659
2016-17	-	8,231	8,231	34,24,672.17	6,84,93,443.4	3,39,05,07,462
2017-18	135	9,693	9,828	40,89,135.96	8,17,82,719.2	4,04,83,42,527
2018-19	-	10,855	10,855	45,16,439.85	9,03,28,797	4,47,13,83,611
2019-20	-	10,160	10,160	42,27,271.2	8,45,45,424	4,18,50,99,722
2020-21	96	12,531	12,627	52,53,715.89	10,50,74,317.8	5,20,13,04,546
2021-22		9,385	9,385	39,04,816.95	7,80,96,339	3,86,58,62,293
2022-23	475	5,233	5,708	23,74,927.56	4,74,98,551.2	2,35,12,35,159
Total	**706**	**76,559**	**77,265**	**3,21,47,648.55**	**64,29,52,971**	**31,82,69,41,932**

**Data provided by NHAI, February 2023*

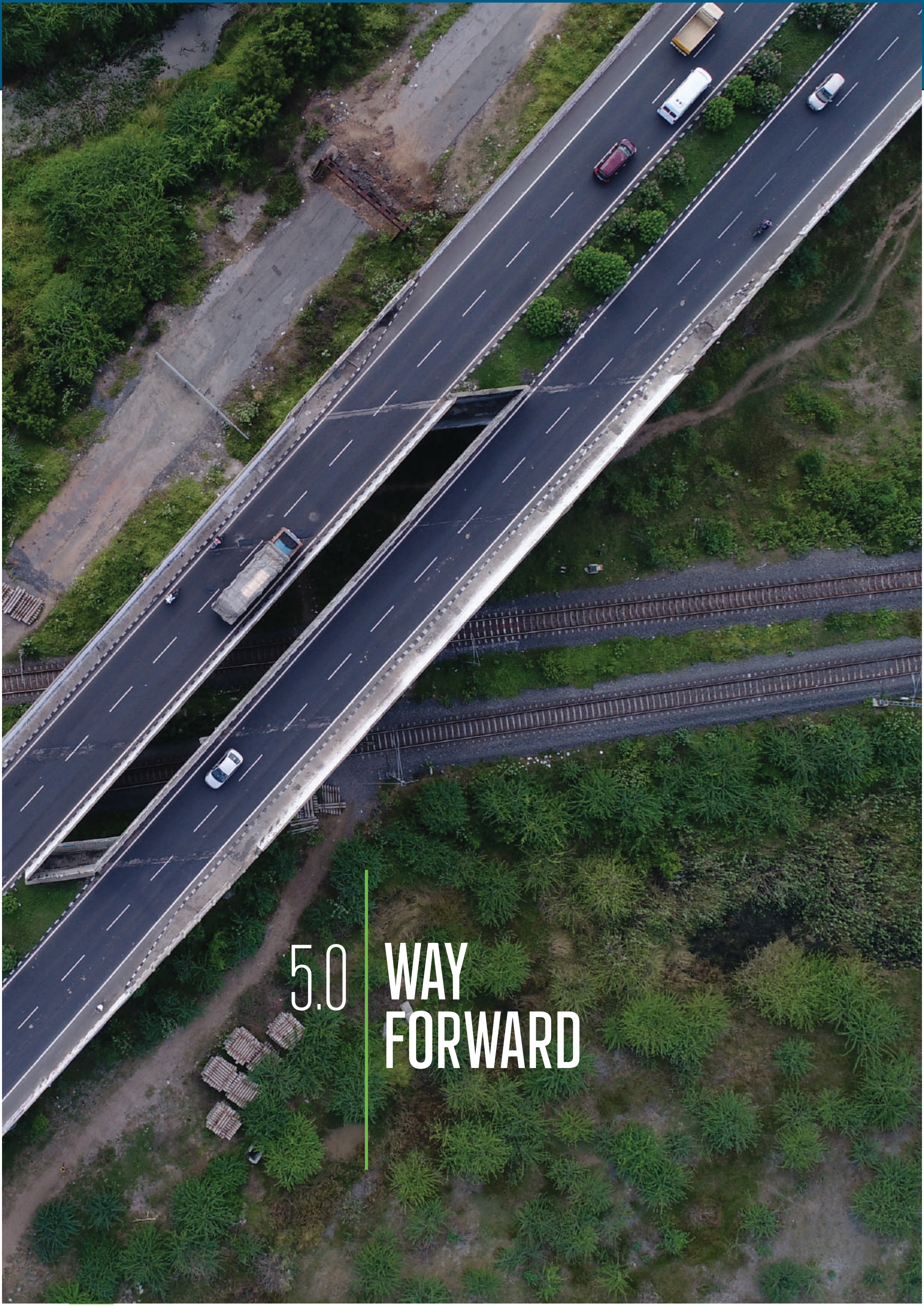

The choice is yours
Saw it or waste it
जल
कल
Save water
Save
Life
Save
Future



4.0 SUMMARY RESULTS

This report presents a methodology for assessing the extent of CO_2 that can be avoided per km of operational highways. Data from 20 NH stretches together extending to a length of 2191.54 kms and located in India's diverse climate zones and topography have been applied to estimate the potential CO_2 that can be avoided by the National highways. Of the 20 National highway stretches considered, 5 are greenfield and 15 are brownfield. The results of this assessment indicates that:

1. Construction of all 20 stretches together have led to an emission of 5716.66 thousand tCO_2 and maintenance has led to an emission of 1164.68 thousand tCO_2
2. Felling of trees outside forests and removal of forests done to pave the way for construction of the highways has led to the emission of 652.60 thousand tCO_2.
3. Fuel consumption by vehicles would have been 50.96 billion litres in a 20 year period if BAU conditions of highways persisted. In the BAU case, the share of petrol in the total fuel consumption would have been 17-19% and diesel share would have been 81-83%.
4. In the Improvement case, when the new highways are operational, it is estimated that the total fuel consumption would be about 41.16 billion litres in a 20 year period. This amount of consumption is less by 19% or 9.77 billion litres of fuel is saved in the improvement case as compared to the BAU case.
5. In the total fuel savings, share of petrol will be about 7% and rest will be share of diesel. The major savings will be 53% and 23% by MCVs and HCVs respectively.
6. For the 20 NH stretches, the savings in petrol range from 2% to 21%, and diesel saving ranges from 1% to 42%. This variation is mainly due to variable conditions of the highways vis a vis their road characteristics (width, roughness etc.) and wide ranging traffic volumes and share of different vehicle types.
7. Therefore due to vehicles plying on the newly constructed and improved highways, it is estimated that in a 20 year period about 25.19 million tCO_2 will be avoided along the entire 2,191.54 kms of NH stretches, which is equivalent to an avoidance of 11,493 tCO_2 per km in 20 years.
   a. In case of Greenfield Highways improvements, the CO_2 avoidance in 20 years can be of the order of 10,167 tons per km whereas
   b. improvements of Brownfield Highways can result in about 11,936 tons per km of CO_2 avoidance.
8. It is estimated that the avenue plantations and compensatory afforestation (CA) done post construction of the highways together potentially can sequester 584.27 thousand tCO_2 over a 20 year period.
9. Adding up the CO_2 emissions and sequestrations streams across all the stretches considered that together extend to a total of 2191.54 kms, it is estimated that potentially 18236.62 thousand tCO_2 over a 20 year period can be avoided. This is equivalent to a potential avoidance of 8321 tCO_2 per km.
10. Based on standard assumptions, it is estimated that a total of 18237.31 thousand tCO_2 emissions avoided across 2191.54 kms of NH in a 20-year period is equivalent to CO_2 sequestered by 997 million trees (See details in Annex 2).
11. Further based on the per km CO_2 sequestration potential estimated, it is inferred that the 77,265 kms of NH constructed since 2014 till date, will potentially avoid 32.15 million tCO_2 annually and 642.95 million tCO_2 cumulatively in next 20 years. This is equivalent to CO_2 sequestration by 36,149 million trees (See Table 13).



5.0 WAY FORWARD

The IPCC Working Group III report of April 2022 on Mitigation of Climate Change highlights concerns around land-use change and explicitly states (Section 7.3.1.2) that "among infrastructural developments, roads are one of the most consistent and most considerable factors in deforestation, particularly in tropical frontiers." The exercise presented herein documents a detailed guidance for estimating tCO_2 avoided per km of NH and can form the basis for tracking CO_2 emitted or avoided due to this activity.

Considering that the IPCC has identified road construction as a major factor for vegetation loss, there is a case for integrating opportunities for enhancing CO_2 avoidance and sequestration in the entire NH construction, operation and maintenance cycle and support development of location and stretch specific per km CO_2 avoidance values for a more rigorous assessment of CO_2 avoided by this sector.

The present assessment is the 1st step towards quantifying the amount of CO_2 emissions avoided due to lower fuel consumption on improved and widened roads of the highways and due to ancillary activities of NH such as plantations done along the roads and the compensatory afforestation. The following sections offer suggestions that would lead to enhanced avoidance and quantification of more scientifically rigorous per km CO_2 avoidance values further leading to bridging of data gaps currently existing.

5.1 Development of Guidance for enhancing CO_2 avoidance for NH system

Further to continuously enhance avoidance of CO_2 emissions from this sector, that would contribute towards India's achievement of NDCs by 2030 as well as towards its C neutral goal by 2070, it is suggested to develop commensurate standard decision tree based location specific SOPs that would integrate the best available green technologies in the entire cycle of NH construction, operation and maintenance. Methods of resource efficiency including the use of affordable green technologies, such as green road materials for roads and sidewalks, green fuel for construction, better practices of highway maintenance, and local climate specific plantations amongst others can be continuously evaluated and integrated. This would be further strengthened by formulation of a strong monitoring and evaluation framework for feedback into the system.

5.2 Road Construction and Maintenance

Resource efficiency, including optimization of pavement design, reducing lead distance of material sources, use of local and recycled materials etc., are major factors that can lead to a reduction in GHG emissions. It is recommended to conduct a comparative assessment study of the alternative technologies and materials in terms of GHG emission prior to decision making to utilize them in road construction. It is also recommended to prioritize the use of carbon-efficient technologies/materials based on site conditions. Few GHG emission-efficient technologies and materials are pointed out in Section 6 of IRC SP 133 (2021) for ready reference.

5.3 NH Operations

As present estimation of fuel consumption on different studies has been done with limited data and some logical assumptions, these can be overtaken by conducting studies on a large number of sections in order to develop a generalized methodology for fuel consumption estimations on NHs. Other direct and indirect impacts due to accidents and road user costs during road construction and operations have to be appropriately considered in order to holistically estimate the savings from the construction or improvements of NHs in the country. Further, traffic growth rates over the design life of NHs need to be considered appropriately and analyzed accordingly to evaluate the overall benefits from NHs.

5.4 Plantation and Afforestation

The limitations of this study are that it is based entirely on proposed plantation data as indicated in the EIAs and the Project Design Documents of NH stretches considered. The study also assumes uniform growth rates and survivals across all the stretches considered. In the actual scenario, however growth rates vary from species to species and across regions. Further, there are data documentation gaps in some stretches, such as the number and species of trees that were felled and are proposed to be planted. The EIA and PDDs of some stretches have not documented complete information separately of avenue trees and total no. of median trees/bushes to be planted, girth of trees to be felled by species and do not report the status of soil C in forest area lost. Data is also not available on the area of CA and the actual number and species planted, including the date of the plantation. No post-plantation monitoring data is available that can provide actual growth rates and survivals or status of soil organic carbon.

It is therefore important that systematic documentation of this data is ensured and access to all plantation information is made available for replantation as and when required. This detailed documentation will capture the species-wise regional diversity in growth rates, and survival rates of the trees planted and, as a loss will enable a more accurate assessment of:

- The extent of carbon loss due to the felling of forest areas and trees outside for road construction using satellite data
- Carbon sequestration due to different avenue tree and median tree species planted
- Carbon sequestration by Compensatory Afforestation
- Lay down agro-climate specific trees for avenue plantation and for CA
- Design avenue plantation monitoring protocol and maintenance protocols to ensure survival at acceptable levels.

Appendix A

Table A1: 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
Ready-mix concrete	0.750
Steel reinforcement	20.100
Other steel	20.100
Bitumen/tar	51.000
Cationic Bitumen emulsion	51.000
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

Fuel Consumption Estimations for Traffic Operations on Selected NHs

Table A2: Fuel Consumption in Litres/Year by different vehicle types on selected NH Sections for BAU Case

S. No.	NH Section	Length (km)	Total Fuel Consumption (BAU) - Million Litres (20 Years)									
			Cars- Petrol	Cars-Diesel	MTW	Auto	Bus	LCV	HCV	MCV	Petrol	Diesel
1	Eastern Peripheral Expressway (EPE) NE-2	104	248.41	141.77	-	1.45	256.58	179.18	236.57	1,071.33	248.41	1,886.89
2	Ahmedabad - Vadodara Expressway (NE-1)	112	164.97	84.71	-	-	60.85	113.71	99.32	182.40	164.97	541.00
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	286	859.25	441.70	-	-	170.42	81.05	617.31	3,215.70	859.25	4,526.18
4	Delhi - Meerut Expressway (NE-3)	60	697.54	409.35	0.34	129.33	70.41	97.93	2.69	1.08	697.89	710.81
5	Chenani-Nashri Tunnel Section (NH-44)	41	24.41	11.55	-	-	41.37	41.50	112.98	235.63	24.41	443.02
6	Delhi - Agra Section (NH-2)	179.5	975.96	494.46	-	0.71	245.40	272.29	398.51	2,091.87	975.96	3,503.24
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	46.45	24.12	-	-	152.82	30.43	-	107.49	46.45	314.86
8	Panipat - Jalandhar Section (NH-44)	291.1	1,935.16	988.03	-	-	1,298.69	1,101.14	-	2,226.76	1,935.16	5,614.62
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	143.67	73.40	-	-	345.61	81.12	101.94	1,896.05	143.67	2,498.11
10	Yedeshi - Aurangabad Section (NH-52)	189.0	239.70	123.96	-	-	126.29	176.29	465.08	745.62	239.70	1,637.24
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	498.90	254.89	-	-	252.95	223.38	519.20	1,789.37	498.90	3,039.79
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.4	137.05	99.51	102.21	61.25	247.37	201.19	2,791.58	3,558.60	239.26	6,959.49
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	290.60	149.13	107.09	92.50	354.07	135.10	1,729.99	787.61	397.69	3,248.40
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	138.49	88.13	9.23	51.69	98.01	132.24	97.36	222.64	147.72	690.07
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.6	496.66	479.30	121.59	188.16	549.70	423.92	1,095.73	543.75	618.25	3,280.56
16	Porbandar to Dwarka Section (NH-51)	117.7	155.19	79.78	26.85	17.12	76.71	74.71	580.89	474.33	182.04	1,303.53
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	2.72	3.59	0.64	-	-	3.16	29.22	12.10	3.36	48.07
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.4	2.96	4.01	0.67	-	-	3.24	33.38	12.21	3.63	52.85
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	692.71	465.67	250.48	406.68	37.27	415.77	101.85	485.57	943.19	1,912.81
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.5	90.64	55.20	12.44	22.12	3.30	13.41	32.06	147.84	103.08	273.92
	Total	**2,245.3**	**7,841.45**	**4,472.25**	**631.53**	**971.02**	**4,387.83**	**3,800.76**	**9,045.67**	**19,807.94**	**8,472.98**	**42,485.47**

'-' represent No data

Table A3: Fuel Consumption in Litres/Year by different vehicle types on selected NH Sections for Improvement Case

S. No.	NH Section	Length (km)	Total Fuel Consumption (Improvement Case) - Million Litres (20 Years)									
			Cars- Petrol	Cars-Diesel	MTW	Auto	Bus	LCV	HCV	MCV	Petrol	Diesel
1	Eastern Peripheral Expressway (EPE) NE-2	136.0	244.62	123.67	-	1.22	209.77	125.09	153.77	698.32	244.62	1,311.83
2	Ahmedabad - Vadodara Expressway (NE-1)	93.3	132.95	66.84	-	-	48.10	98.23	81.43	143.08	132.95	437.67
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227.0	823.10	412.46	-	-	134.07	83.91	479.08	2,177.43	823.10	3,286.95
4	Delhi - Meerut Expressway (NE-3)	82.0	615.11	359.53	0.48	187.17	66.87	83.88	2.90	1.23	615.59	701.59
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	19.18	9.08	-	-	32.52	35.27	96.30	187.46	19.18	360.63
6	Delhi - Agra Section (NH-2)	179.5	960.43	483.02	-	0.70	237.66	272.30	373.24	1,908.14	960.43	3,275.05
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	41.98	21.41	-	-	136.18	28.15	-	95.26	41.98	281.01
8	Panipat - Jalandhar Section (NH-44)	291.1	1,883.11	948.90	-	-	1,229.29	1,110.71	-	2,009.05	1,883.11	5,297.95
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	135.74	68.24	-	-	271.88	81.12	80.79	1,322.16	135.74	1,824.19
10	Yedeshi - Aurangabad Section (NH-52)	189.0	223.30	113.03	-	-	98.32	172.62	360.37	508.63	223.30	1,252.98
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	470.42	237.59	-	-	203.50	223.03	413.42	1,241.59	470.42	2,319.13
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.4	123.11	89.29	90.73	60.52	186.13	198.59	2,222.70	2,560.41	213.85	5,317.65
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	284.76	143.55	106.31	84.74	188.55	88.40	981.99	395.54	391.07	1,882.77
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	121.99	73.77	6.43	45.17	75.57	125.64	92.63	152.24	128.42	565.02
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.6	424.97	367.64	100.11	146.47	407.39	336.62	843.09	464.51	525.07	2,565.71
16	Porbandar to Dwarka Section (NH-51)	117.7	152.78	77.17	26.38	16.48	64.44	72.09	482.05	343.11	179.15	1,055.35
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	2.64	3.50	0.58	-	-	2.99	27.70	10.28	3.22	44.48
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.4	2.83	3.76	0.61	-	-	3.17	29.80	10.86	3.44	47.60
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	616.82	405.05	130.29	360.75	35.46	208.85	56.75	241.64	747.11	1,308.49
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.5	76.28	46.08	10.34	18.38	2.67	11.13	26.36	116.03	86.62	220.65
	Total	**2,191.5**	**7,356.12**	**4,053.58**	**472.26**	**921.60**	**3,628.38**	**3,361.77**	**6,804.40**	**14,586.98**	**7,828.38**	**33,356.70**

'-'represent No data

Table A3: Fuel Consumption in Litres/Year by different vehicle types on selected NH Sections - Fuel Savings

S. No.	NH Section	Length (km)	Total Fuel Consumption (Savings) - Million Litres (20 Years)									
			Cars- Petrol	Cars-Diesel	MTW	Auto	Bus	LCV	HCV	MCV	Petrol	Diesel
1	Eastern Peripheral Expressway (EPE) NE-2	136.0	3.78	18.11	-	0.24	46.81	54.10	82.80	373.01	3.78	575.06
2	Ahmedabad - Vadodara Expressway (NE-1)	93.3	32.03	17.87	-	-	12.76	15.49	17.89	39.32	32.03	103.33
3	Ismailabad - Narnual Section (Trans Haryana) NH-152D	227.0	36.15	29.25	-	-	36.35	-2.86	138.23	1,038.27	36.15	1,239.23
4	Delhi - Meerut Expressway (NE-3)	82.0	82.43	49.83	-0.13	-57.84	3.54	14.05	-0.21	-0.15	82.30	9.21
5	Chenani-Nashri Tunnel Section (NH-44)	10.8	5.23	2.46	-	-	8.86	6.23	16.67	48.16	5.23	82.38
6	Delhi - Agra Section (NH-2)	179.5	15.53	11.45	-	0.01	7.74	-0.00	25.27	183.73	15.53	228.19
7	Chennai Madurai Highway (Tindivanam to Ulundurpet Section) NH-45	72.9	4.46	2.70	-	-	16.64	2.28	-	12.23	4.46	33.85
8	Panipat - Jalandhar Section (NH-44)	291.1	52.05	39.13	-	-	69.40	-9.57	-	217.71	52.05	316.67
9	MP/MH Border to Jamtha on Nagpur Bypass Section (NH-44)	94.9	7.93	5.16	-	-	73.73	-0.00	21.15	573.89	7.93	673.93
10	Yedeshi - Aurangabad Section (NH-52)	189.0	16.40	10.92	-	-	27.97	3.67	104.71	236.99	16.40	384.27
11	Hyderabad Bangalore Highway (Thondupalli to Kurnool Section) NH-44	188.4	28.47	17.30	-	-	49.44	0.35	105.77	547.78	28.47	720.66
12	Pune Solapur Highway (Yavat - Temburni Section) NH-65	104.4	13.93	10.21	11.48	0.73	61.23	2.60	568.88	998.18	25.41	1,641.84
13	Ranchi-Hazaribagh-Barhi Section (NH-33)	114.0	5.84	5.58	0.78	7.76	165.53	46.70	748.00	392.07	6.62	1,365.64
14	Guwahati to Nagaon Highway (Khanpara - Dharamtul Section) NH-27	66.6	16.51	14.36	2.79	6.52	22.43	6.60	4.73	70.40	19.30	125.05
15	Walayar (KL/TN border) - Edapally Section (NH-544)	124.6	71.70	111.66	21.48	41.69	142.31	87.30	252.64	79.25	93.18	714.85
16	Porbandar to Dwarka Section (NH-51)	117.7	2.42	2.60	0.47	0.64	12.27	2.62	98.84	131.21	2.89	248.19
17	Pasighat to Bomjur, Arunachal Pradesh (NH-13)	22.2	0.07	0.09	0.07	-	-	0.17	1.52	1.82	0.14	3.59
18	Pasighat – Yingkiang Road (Singer River – Sizoh Nala Section), Ar.P (NH-513)	23.4	0.13	0.25	0.05	-	-	0.07	3.58	1.35	0.19	5.25
19	Delhi Dehradun Expressway (Akshardham - Kekhra Section)	31.2	75.89	60.62	120.19	45.94	1.82	206.93	45.09	243.94	196.08	604.33
20	Banihal Jammu Highway (Quazigund - Banihal Section) NH-1A	22.5	14.36	9.11	2.10	3.74	0.64	2.28	5.69	31.81	16.46	53.26
	Total	**2,191.5**	**485.33**	**418.67**	**159.27**	**49.43**	**759.45**	**439.00**	**2,241.27**	**5,220.96**	**644.60**	**9,128.77**

'-' *represent No data*

Appendix B

To calculate the equivalent number of trees that can sequester the net CO_2 emissions from National Highways, the following equation has been used:

No. of equivalent trees = CO_2 avoided annually/ (C to CO_2 conversion ratiox BF x GRB x no. of trees /ha)

Where

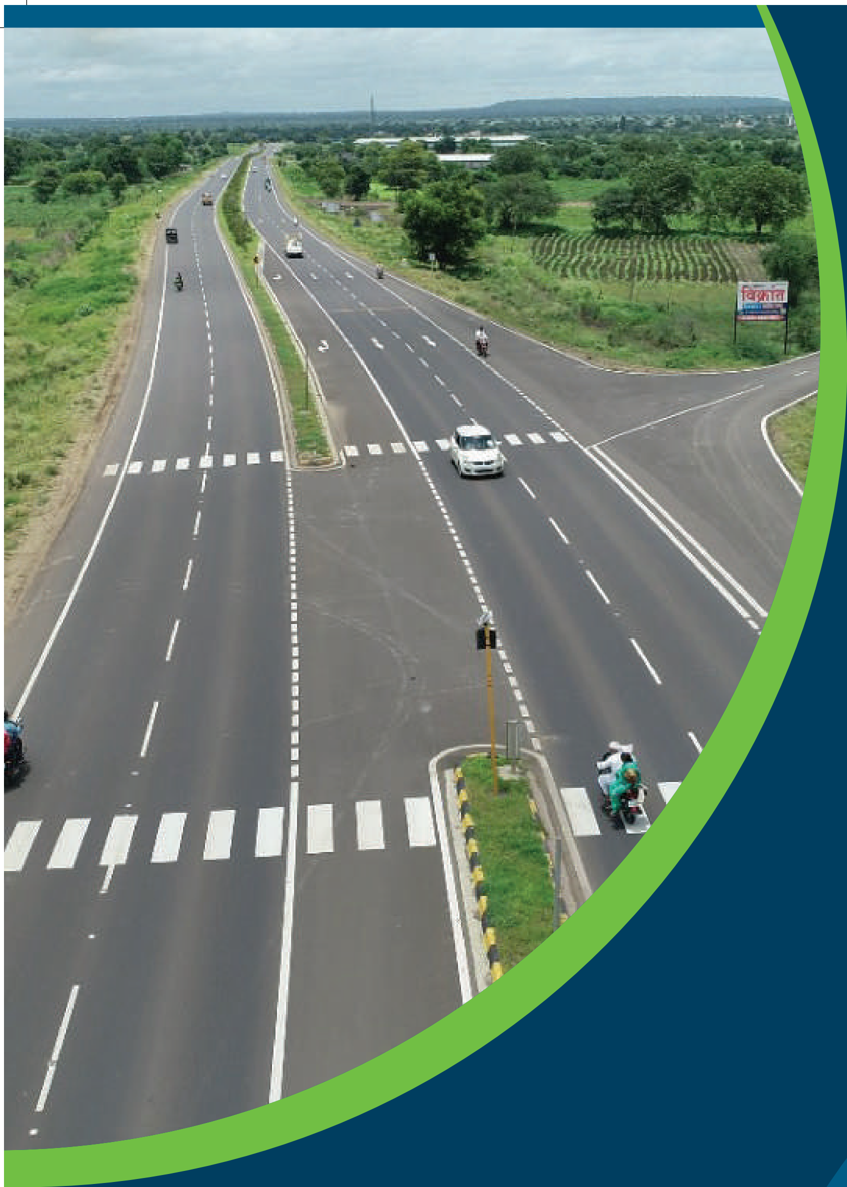
- CO_2 avoided annually = CO2 avoided across all stretches in 20 year period
- C to CO_2 conversion factor = 3.67
- Biomass content in dry matter: 0.47
- tonnes dry matter in biomass= 7.8 tons dm/ha/year
- no. of trees planted per ha = 666

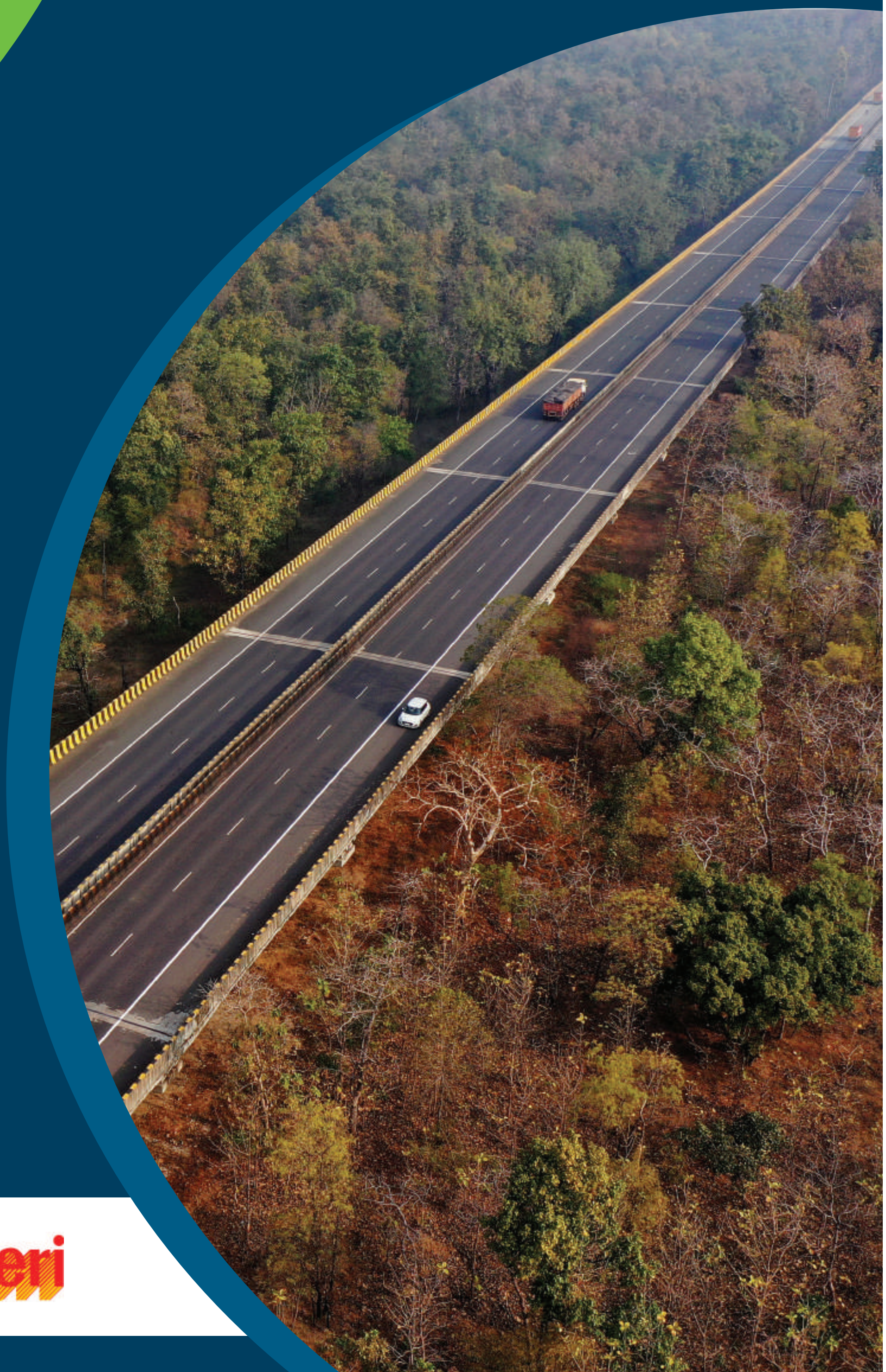
The following table estimates the number of trees using equation above

Table B1: Number of trees that can sequester equivalent amount of CO_2 avoided due to NH construction and operations*

Tonnes of CO_2 avoided in 20 years	Tonnes of CO_2 avoided annually	Equivalent tons C avoided annually	Equivalent Biomass	Equivalent Hectares of Plantation	Equivalent no. of trees that need to be planted
A	B	C	D	E	F
1,82,36,616.3	9,11,830.8	2,48,455.263	5,28,628.219	67,772.84853	4,51,36,717.12

**Here the tCO_2 avoided in 20 years has been taken from Table 12 for the average growth rate scenario and 20% mortality*





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