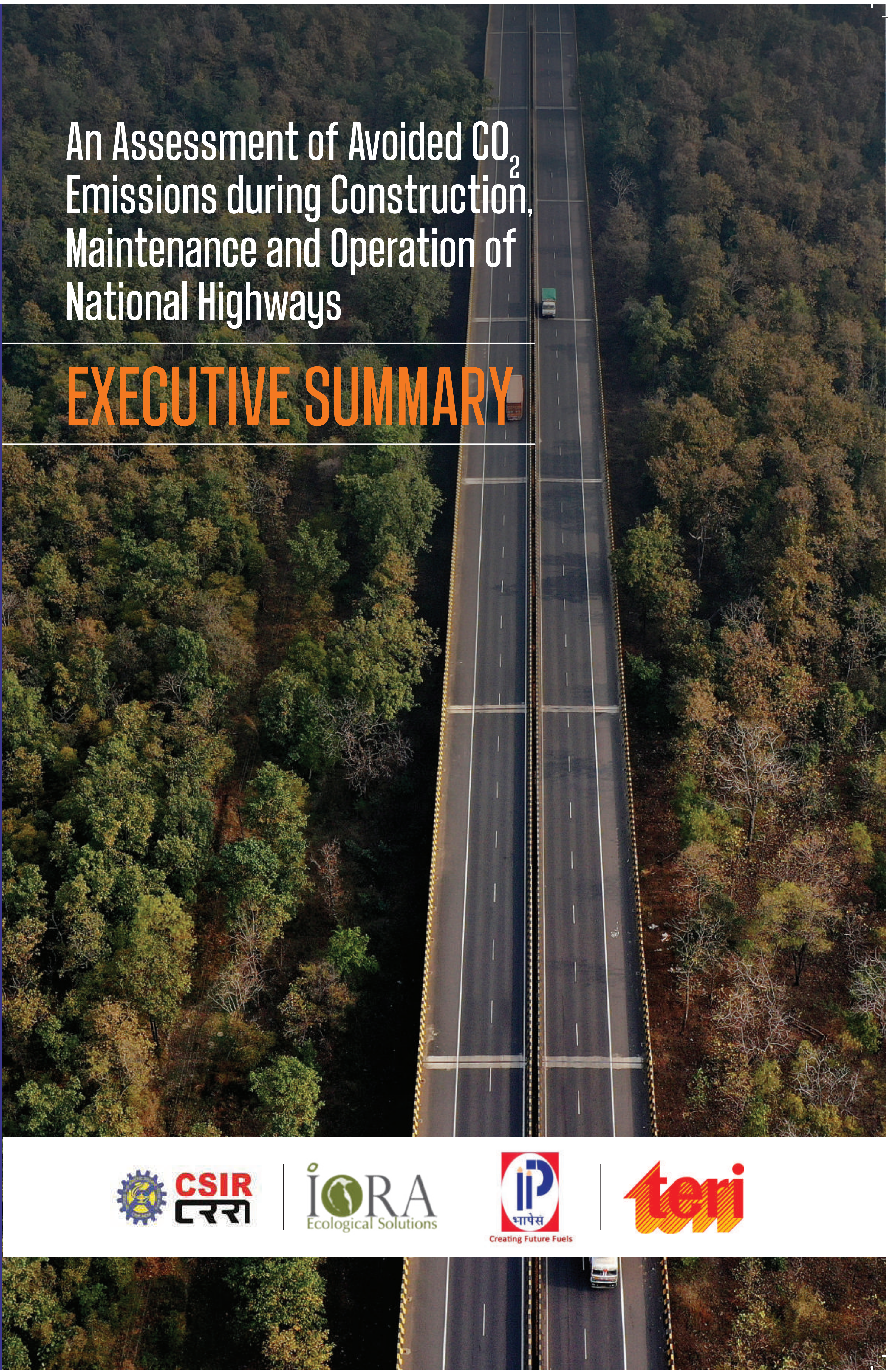
An Assessment of Avoided CO_2 Emissions during Construction, Maintenance and Operation of National Highways

EXECUTIVE SUMMARY



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About the Study

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 km)[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 million tonnes 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.

This summary report presents a methodology for assessing the extent of CO_2 that can be avoided per km of national highways constructed. Further, pre-construction and actual operation and maintenance data of national highways have been applied to quantify the CO_2 avoidance per km of NH constructed.

1 https://pib.gov.in/PressReleseDetailm.aspx?PRID=1888480#:~:text=As%20on%2030%20November%20 2022,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

Scope of the Study

The 20 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 green field 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

S. No.	NH Section	Length (km)	No. of Lanes	Pavement Type (BT/CC)
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

Construction and Maintenance

There are multiple methods available for estimating carbon footprint during the construction and maintenance phases of infrastructure development. The key methods available include:

01 **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 green-house gas (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.

02 **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.

03 **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:

01 This approach is data intensive and complies with greenfield as well as brownfield projects.

02 It systematically records and analyses the carbon emissions.

03 Widely accepted to estimate the carbon footprint of infrastructure sectors, especially roads.

04 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 Energy and Resources Institute (TERI) has developed a tool to estimate emissions for different representative projects/stretches, which generate highway-level emissions and factors for different types of highways during the construction and maintenance phases.

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

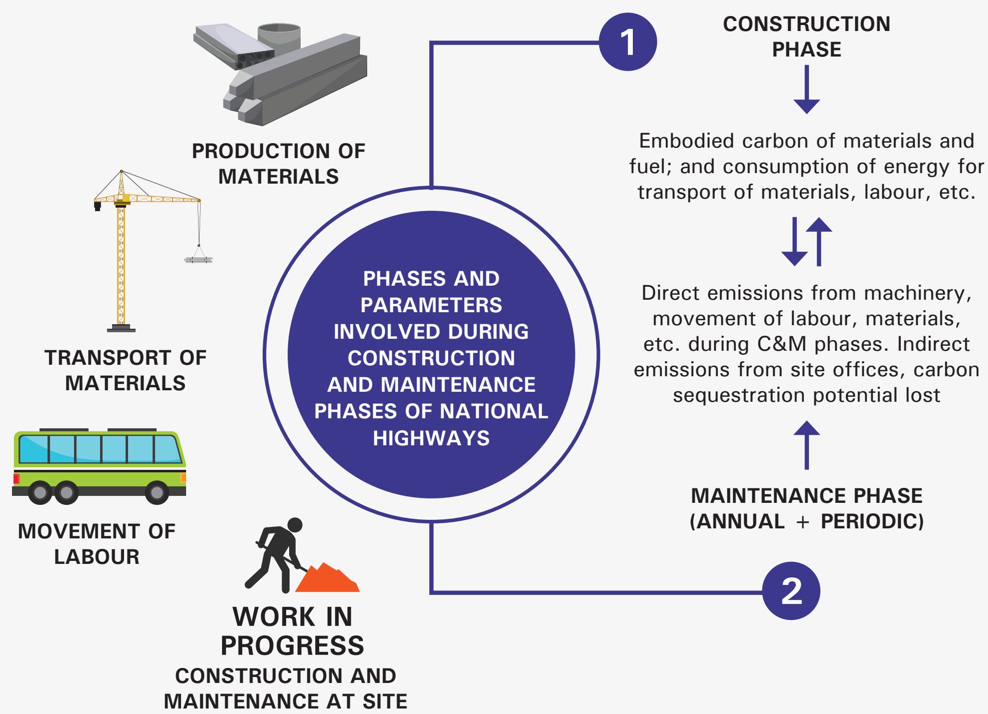


Figure 1: Phases and processes involved while calculating CO_2 emissions due to construction and maintenance of highways; Source: TERI

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))

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

1. 100 km lead distance assumed for construction materials
2. Construction materials are carried by 25-tonne vehicle with 4.42 kmpl fuel efficiency (Diesel)
3. Density of compacted Granular Sub Base (GSB): 2200 kg/m^3, Base: 2200 kg/m^3, Bituminous and concrete layer: 2400 kg/m^3
4. 350 kg of cement for one cubic meter of concrete (pavement quality concrete)
5. For fuel consumption, the following factors have been considered:
   - On-site electricity consumption
   - Diesel consumption (generators, machinery and vehicles)
   - Petrol consumption (vehicles and machinery)
   - Others, including the consumption of kerosene, LPG, natural gas and biomass at the site

Results

Using the LCA tool and data provided by NHAI, TERI calculated the total emissions using the above methodology on account of construction and maintenance activities. The total CO_2 emissions from the construction phase for the 20 National Highway stretches range from 16,880 tonnes of CO_2 to 30.4 lakh tonnes of CO_2. Similarly, for the maintenance phases, CO_2 emissions range from 33,430 tonnes of CO_2 to 6.5 lakh tonnes of CO_2. Notably, the accuracy of the result is dependent on the input parameters, namely the quantity of materials consumed, fuel consumption at site, and energy consumption for the movement of materials, staff/labour, etc. As seen in **Table 2**, the values for construction and maintenance of per lane km of NH vary across stretches as information provided by the National Highways Authority of India (NHAI) is limited in nature.

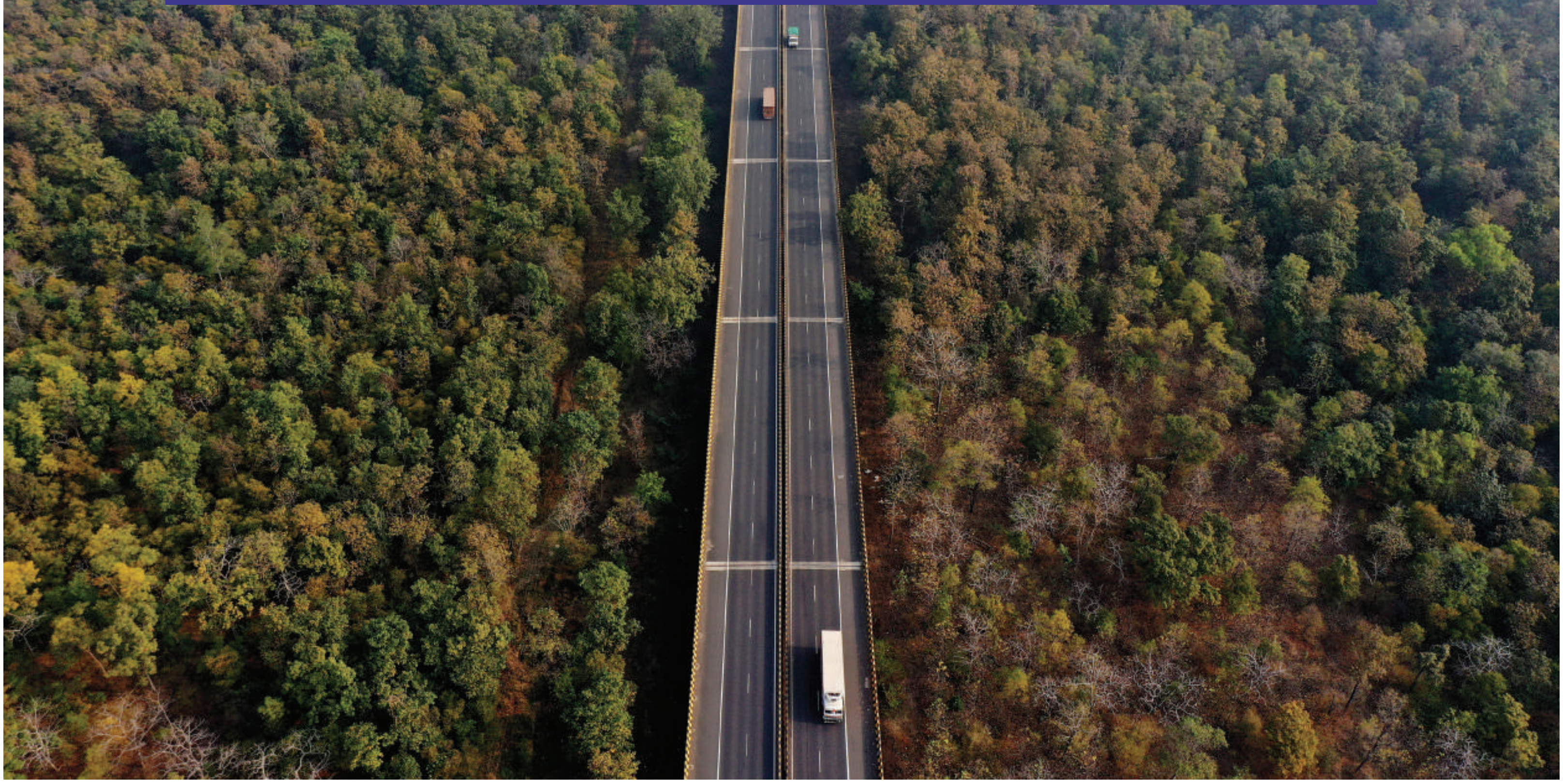


Table 2: CO_2 Emissions during Construction and Maintenance Phases

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

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
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

Traffic Operations Phase

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 Indian Roads Congress (IRC) guidelines (IRC SP 30, 2019).[4] 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 for different vehicle types.

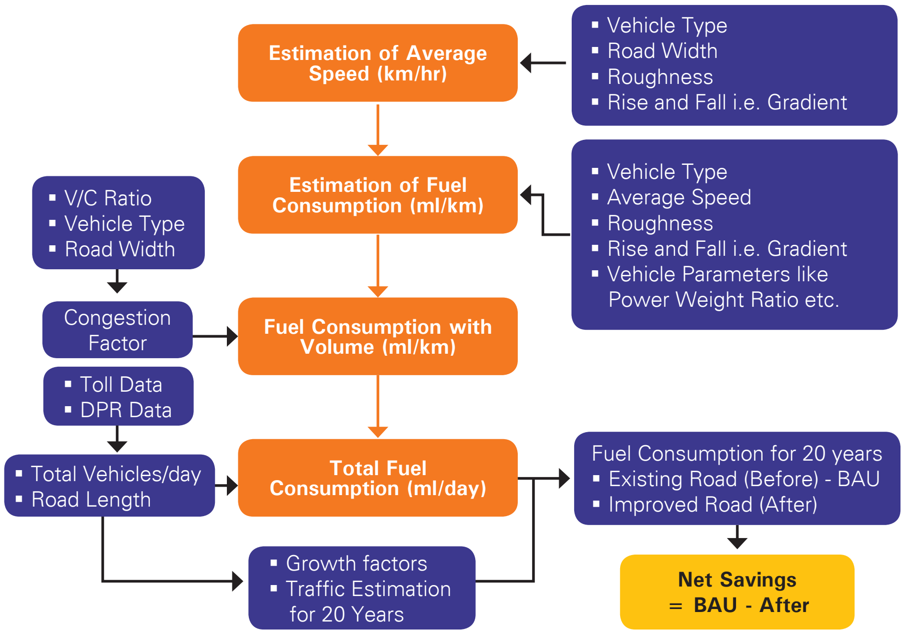


Figure 2: Adapted methodology for estimation of fuel consumption during traffic operations on national highways; Source: CSIR-Central Road Research Institute (CRRI)

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

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, volume/capacity (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 which in turn is converted into yearly and also for the period of 20 years using yearly traffic growth factors. These estimations have been made for alternate scenarios i.e. business as usual (BAU) and improved conditions (new constructions and widening). Accordingly, the net savings in CO_2 emissions have been estimated from these. For estimation of fuel consumption by different vehicles during traffic operation, the following assumptions have been made:

01 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.

02 As fuel consumption equations are available for vehicles of petrol and diesel only, so estimations are done for these fuel types only in this study.

03 Toll data has been considered to determine total daily traffic volume wherever it is available on that section of highway, all limitations with respect to toll data are applicable, especially non-inclusion of local traffic.

04 As the peak hour phenomenon could not be observed in toll data because of the discharge of the vehicles from toll booths depend on service time which is almost same, hence peak hour in terms of no. of congested hours prevailing on the sections have been considered appropriately for estimation of Congestion Factors.

05 V/C ratio appropriately considered from Peak hour factor of 10%.

06 Classified traffic volume considered in all the analyses is provided by NHAI from available detailed project reports (DPR). All limitations of those DPRs are applicable to this study.

07 Generated traffic (route shift and induced traffic) is not explicitly considered.

The estimated quantity of fuel saved/ avoided, i.e. Petrol and Diesel due to new construction (Greenfield highway) and widening (Brownfield highway) of NH have been converted into CO_2 emissions by using fuel-based IPCC emission factors (IPCC,1996 and IPCC, 2006).[5] 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).[6]

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

[6] 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.

Results of Fuel consumption due to traffic operations

Utilizing the above methodology with assumptions, the results in terms of fuel consumption for a total of 20 Nos. of NH sections have been estimated for a 20-year period in the cases of BAU and Improvement. 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 has 17% share of Petrol and 83% share of Diesel. In the case of Improvement scenario, it can be inferred that the estimated total fuel consumption is about 41.16 billion litres (in 20 years) which has 19% share of Petrol and 81% share of Diesel. It can also be inferred from these results that about 19% of reduction in fuel consumption (9.77 billion litres) has been observed compared to the BAU case in 20 years. The calculated fuel saved from the improvement of NH is shown in **Figure 3**, and the share of different vehicle types in fuel savings is shown in Figure 4. It can be seen from **Figure 4** that major fuel consumption (savings) has been observed from the vehicle types of Multi-Axle Commercial Vehicles (MCV) and 2-Axle Heavy Commercial Vehicle (HCV), i.e. 53% and 23%, respectively.

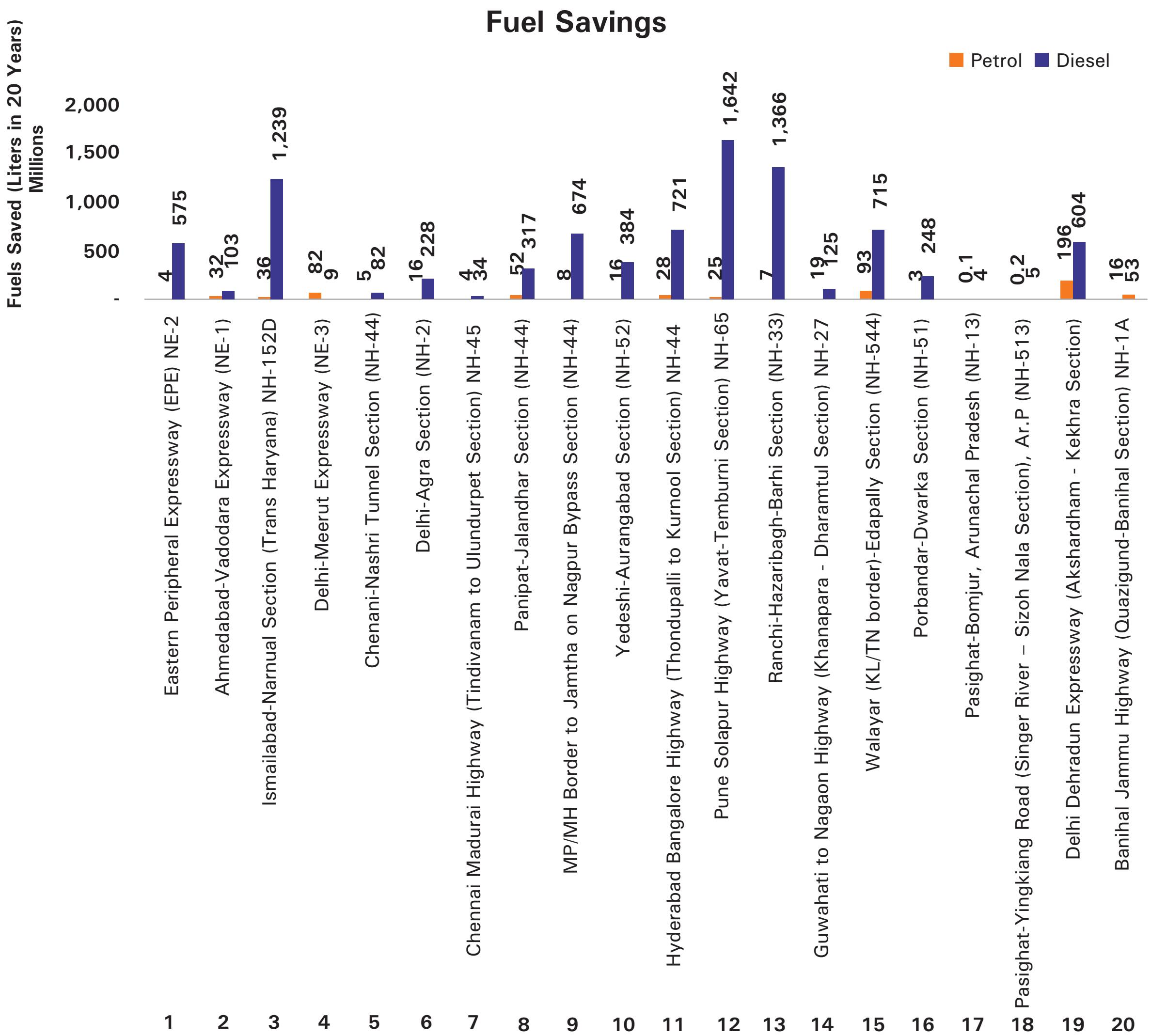


Figure 3: Estimated fuel savings on different NH sections after improvement; **Source:** CRRI

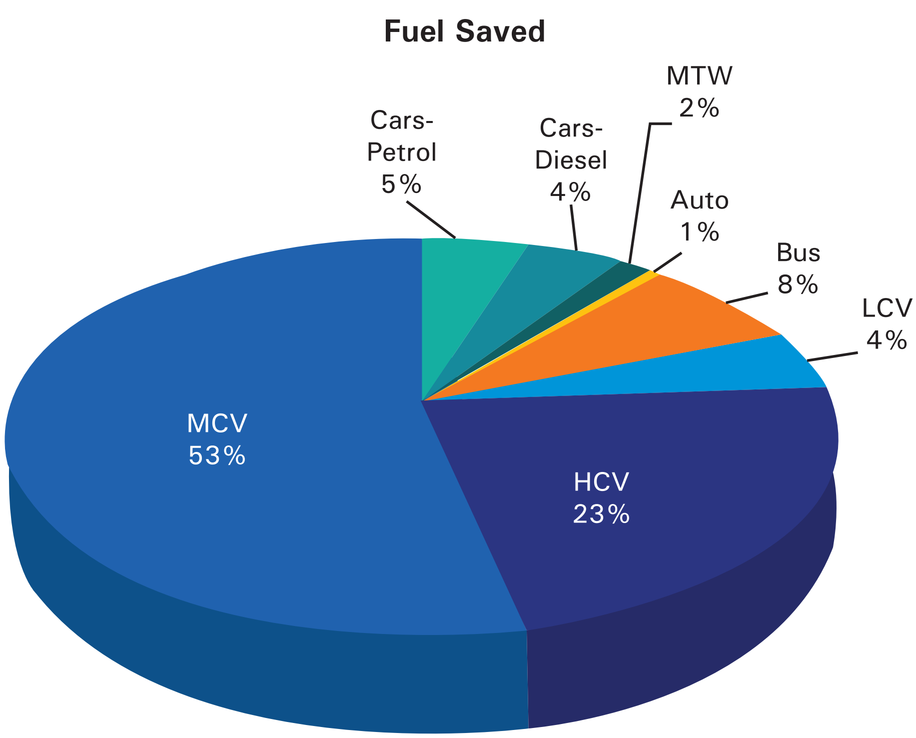


Figure 4: Share of fuel savings of different vehicle types after improvement; **Source:** CRRI

The estimated fuel consumption savings in 20 years for the selected NH sections is about 9.77 billion litres, which has a share of 7% Petrol and 93% Diesel. The savings in petrol have 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.

Results of CO_2 emissions avoided due to traffic operations

Based on the fuel consumption and fuel savings estimated as explained in the previous section, the CO_2 emission saved in tonnes have been estimated for different sections of NH. The total CO_2 saved in 20 years is about 25.19 million tonnes for the road length of 2,191.5 km which is coming out to be about 11,493 tonnes per km. The variation of avoided CO_2 emissions for different NH sections is presented in **Figure 5**.

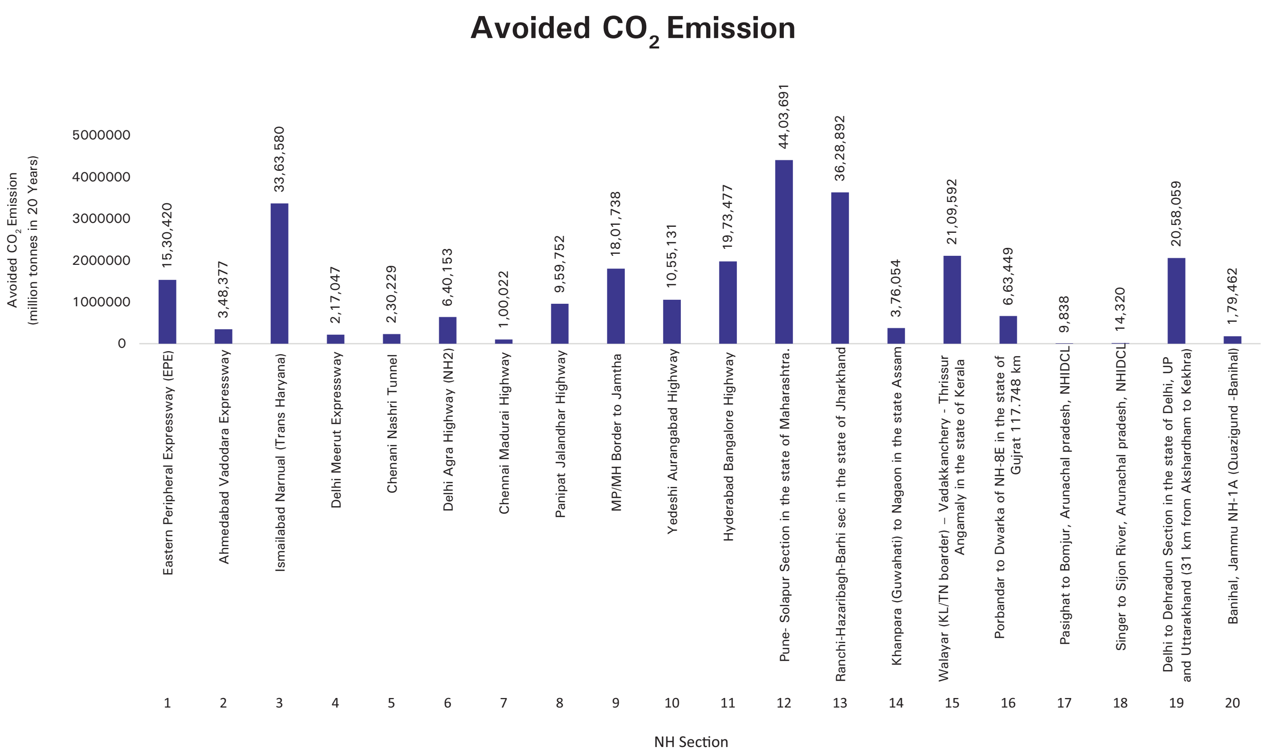


Figure 5: Estimated avoided CO_2 emissions on different NH sections due to improvement; **Source:** CSIR - IIP

Carbon Loss due to Loss of Green Cover

Green cover here refers to forest area and trees outside forests (ToF). Clearing of forests and felling of ToF for construction of National Highway leads to CO_2 emissions. For all the 20 stretches considered in the present assessment, total area of forest loss amounted to 2,179.40 ha or 2.18 thousand ha and total equivalent area of TOF felled was around 32,698.90 ha or 32.70 thousand ha. Data pertaining to loss in forest area and TOFs felled is sourced from the EIAs and DPRs of NHAI for the corresponding projects. The Carbon stock for Above Ground Biomass (AGB), Below Ground Biomass (BGB), and Soil Organic Carbon (SOC) have been taken from the FSI publications on state-wise forest carbon stock and trees outside forest.[7]

CO_2 emitted from loss of green cover =

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

Here i indicates the stretches of NH

and

44/12 is the conversion factor for converting carbon to CO_2

[7] 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; 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

The Carbon loss in AGB, BGB and SOC for all the 20 stretches together is estimated to be 42.85, 14.23 and 184.72 thousand tonnes respectively, and the combined CO_2 emission is 652.60 thousand tonnes. **Table 3** details stretch by stretch carbon loss by each pool and total CO_2.

Table 3: CO_2 emitted due to Tree felling and forest area loss

S. No.	NH Section	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
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

S. No.	NH Section	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)
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

Carbon Sequestration Phase

CO_2 sequestration by Avenue Plantations and Compensatory Afforestation

Avenue plantations, median plantations and CA offer CO_2 sequestration opportunities to offset Carbon loss due to felling of trees and clearance of forests during NH construction. These are done as per the guidance of the Green National Highway Policy (2015).[8] **Equation 3** presents the methodology to estimate the total CO_2 that can be sequestered by these plantations over a 20-year period. The period of sequestration chosen here is in line with the IPCC GPG (2003)[9] default for stored carbon to reach 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.

Total CO_2 sequestered =

$\Sigma^{n}_{i=1}\{[(C \text{ in AGB} + C \text{ in BGB} + SOC) \times (44/12)] \times 20\}$ ……………………………………(2)

Where

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

Carbon in BGB = tonnes of dry matter in AGB x R

SOC = C in (AGB+ BGB) x OCS ……………………………(3)

8 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

9 IPCC 2003. Good Practice Guidance for Land Use Land Use Change and Forestry. Accessed from: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

Here
CA= Compensatory Afforestation
AP = Avenue Plantation
MP= Median Plantation
dm = dry matter

C = Carbon
R = Ratio of BGB to AGB = 0.27[10]
CF = Carbon Fraction of Dry matter = 0.47
OCS = Organic Carbon content of Soil =0.5
n = number of stretches

Data on compensatory afforestation is available in terms of number of trees proposed to be planted or area to be planted or the Net Present Value (NPV) of the diverted forest land. The NPV value if available, is converted to ha by considering per sapling cost of Rs 250 and 1000 saplings per ha. This includes maintenance cost as well. Information on the number of trees planted if available is converted to the equivalent area of plantation assuming a minimum of 1000 trees per ha which is within the guidance range of 1000-2500 plants/ha8.

Three scenarios of growth and mortality rates have been assumed to capture the variability in these that can occur. It is estimated that cumulative CO_2 sequestration potential in a 20-year period of all the 20 stretches with zero mortality and the maximum AGB growth rate of 13.5 t dm/ha/yr, will be 804.30 thousand tonnes of CO_2. For the worse-case scenario if the plantation grows at the lowest AGB growth rate (2 tdm/ha/year) and highest mortality rate of 40%, it will allow sequestration of the order of 419.25 thousand tonnes of CO_2 cumulatively along these 20 stretches in 20 years. 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 tonnes of CO_2 for all the stretches put together in a 20-year period (See Table 5).

[10] IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Table 4: Potential CO_2 sequestration due to avenue plantation and Compensatory Afforestation in next 20 years with Three biomass growth rate and mortality scenarios

Biomass Growth Rates	CO_2 sequestration in (tonnes of CO_2)		
	0% mortality	20% mortality	40% mortality
Best case scenario with AGB growth rate of 13.5t dm/ha/yr	8,04,302	6,43,441	5,14,753
Average case scenario with AGB growth rate of 7.8 t dm/ha/yr	7,30,340	5,84,272	4,67,418
Low Case scenario with AGB growth rate of 2.0 t dm/ha/yr	6,55,082	5,24,065	4,19,252

Source: IORA

A stretch by stretch sequestration potential is presented in Table 4 for an average AGB growth rate scenario (7.8 t dm/yr). It indicates that cumulatively CO_2 sequestration by all the stretches would be 730.34 thousand tonnes of CO_2, 584.27 thousand tonnes of CO_2 and 467.42 thousand tonnes of CO_2 in case of zero mortality, 20% mortality and 40% mortality are registered respectively.

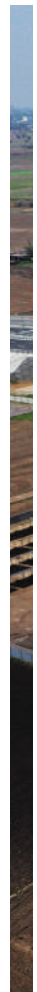
Table 5: Estimated CO_2 sequestered in a 20-year period due to avenue plantation and Compensatory Afforestation

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

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)
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
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**

NO= Not Occurring, NE = Not Estimated, ND = No Data; **Source:** IORA

Result Summary



This report presents a methodology for assessing the extent of CO_2 that can be avoided per km of operational highways. Data from 20 National Highways together extending to a length of 2191.5 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 National Highways. Of the 20 National Highway stretches considered, 5 are greenfield and 15 are brownfield. The results of this assessment indicate that:

01 Construction of these stretches together have led to an emission of 5,717 thousand tonnes of CO_2 and maintenance of the roads led to an emission of 1,165 thousand tonnes of CO_2

02 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 653 thousand tonnes of CO_2.

03 Fuel consumption by vehicles would have been 51 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%.

04 In the Improvement case, when the new highways are operational, it is estimated that the total fuel consumption would be about 41.2 billion litres in a 20-year period. This amount of consumption is less by 19% or 9.8 billion litres of fuel is saved in the improvement case as compared to the BAU case.

05 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.

06 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.

07 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 2,191.5 kms of NH stretches, which is equivalent to an avoidance of 11,493 tonnes 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

08 It is estimated that the avenue plantations and compensatory afforestation done post construction of the highways together potentially can sequester 584.27 thousand tonnes of CO_2 over a 20-year period.

09 Adding up the CO_2 emissions and sequestrations streams across all the stretches considered that together extend to a total of 2191.5 kms, it is estimated that potentially 18,237 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 thousand tonnes of CO_2 emissions avoided across 2191.5 kms of NH in a 20-year period is equivalent to CO_2 sequestered by 45 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 tonnes of CO_2 cumulatively over a period of 20 years. This is equivalent to CO_2 sequestration by 31,826 million trees.

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.

1. Development of Guidance for enhancing CO_2 avoidance for NH system

In order to continuously enhance avoidance of CO_2 emissions from this sector, it is suggested to develop decision-tree based SOPs that would integrate the best available green technologies in the entire cycle of NH construction, plantation, 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, ensuring the sector's contribute towards India's 2030 NDCs and its 2070 carbon neutral goal.

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)[11] for ready reference.

3. NH Operations

As present estimation of fuel consumption on different sections 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.

[11] IRC: SP:133-2021. Guidelines on Reducing the Carbon footprint of road projects. The Indian Roads Congress (IRC), New Delhi, 2021

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 carbon 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:

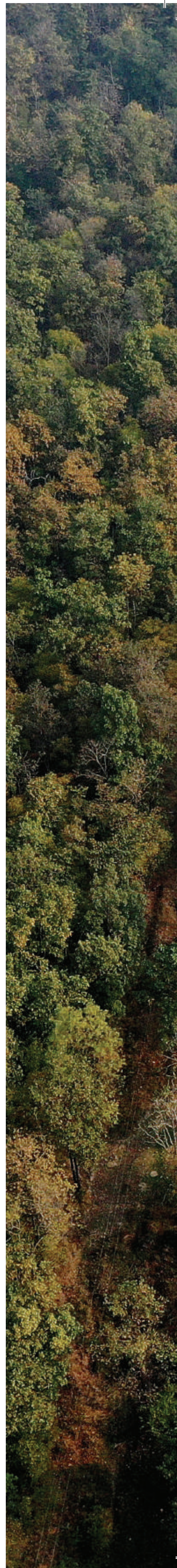
a. The extent of carbon loss due to the felling of forest areas and trees outside for road construction using satellite data
b. Carbon sequestration due to different avenue tree and median tree species planted
c. Carbon sequestration by Compensatory Afforestation
d. Lay down agro-climate specific trees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

Table 6 below, indicates year on year length of NHs constructed since 2014 till date, which amounts to a total of 77,265 kms. Based on the CO_2 avoided per km value estimated, it is concluded that the highway length constructed since 2014 till date can together potentially avoid 32.15 million tonnes of CO_2 annually and 642.95 million tonnes of CO_2 cumulatively in next 20 years. This is equivalent to CO_2 sequestration by 36,149 million trees.

Table 6: CO_2 emissions avoided by the NH constructed since 2014 and equivalent trees

Year	Length of NH Constructed annually*	CO_2 avoided annually	CO_2 that can be avoided in next 20 years	Equivalent no. of trees
	Km	Tonnes	Tonnes	No.
2014-15	4,410	18,34,868	3,66,97,374	2,00,63,94,887
2015-16	6,061	25,21,800	5,04,36,005	2,75,75,41,817
2016-17	8,231	34,24,672	6,84,93,443	3,74,48,15,492
2017-18	9,828	40,89,135	8,17,82,719	4,47,13,94,321
2018-19	10,855	45,16,439	9,03,28,797	4,93,86,43,198
2019-20	10,160	42,27,271	8,45,45,424	4,62,24,42,643
2020-21	12,627	52,53,715	10,50,74,317	5,74,48,40,872
2021-22	9,385	39,04,816	7,80,96,339	4,26,98,44,902
2022-23	5,708	23,74,927	4,74,98,551	2,59,69,39,233
Total	77,265	3,21,47,648	64,29,52,971	36,14,99,27,446

*Data provided by NHAI, February 2023



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