Ministry of Road Transport and Highways

World Bank Technical Assistance Program

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

Executive Summary

teri
The Energy and Resources Institute

About the study

The development of highways is critical for any country for faster movement of passengers and freight, leading to increased national productivity and socio-economic growth. India has for long realised the importance of highways and has been giving an impetus to accelerated development of National Highways (NHs) in the country. The Government of India has launched various programmes to build new highways and improve and upgrade existing highways in order to meet the ever growing transport demand. The target is to construct 20 km on a daily basis.

The construction and subsequent use of highways has implications in terms of increased use of energy and generation of carbon dioxide (CO_2) emissions.

There is a growing realization that the transport sector, especially the NH sector, should bring down its dependence on fossil fuels and reduce its carbon footprint. Additionally, the sector is also required to build resilience to climate change impacts in order to reduce risks and protect the highway infrastructure from impacts of climate change, such as sea-level rise, extreme precipitation, rising temperature, and climate induced extreme events. This requires an understanding of the carbon emissions emitted from the highway sector and an assessment of vulnerability of NHs to extreme weather events induced by climate change.

Realizing the importance of both carbon mitigation and building resilient infrastructure, the Ministry of Road Transport and Highways (MoRTH), Government of India, has commissioned this study to The Energy and Resources Institute (TERI). Aim of the study is to estimate the carbon emissions from the National Highways sector (from construction, operations, and maintenance activities) and recommend methods to reduce the same, and to suggest methodologies and interventions to assess and reduce vulnerability of the highways sector to climate change-induced extreme weather events. The study is divided into two components:

- **Component I** of the study focusses on estimating and suggesting measures to reduce the carbon footprint of NHs sector
- **Component II** of the study focusses on suggesting methodology for assessing and enhancing climate resilience of the NHs sector

Component I
Reducing Carbon Footprint of National Highways

Introduction

India's transport sector contributed about 14% of total energy-related CO_2 emissions in 2010, of which, road transport is estimated to contribute about 88% (Figure 1). NHs are expected to have a higher share in the road sector emissions, as they move almost 40% of the total road traffic despite, constituting only 2% (103,933 km, as on March 31, 2017) of India's total road length (MoRTH, 2015-16).

Given the increasing length/capacity of the NHs network and the increasing volumes of traffic on highways, CO_2 emissions from highways (on account of construction, maintenance, and operation activities) are expected to continue increasing in a business-as-usual scenario, if interventions are not made to mitigate the same.

To establish a low carbon highway sector in the country, it is important to estimate and understand the carbon footprint/carbon emissions profile of the highway sector in order to arrive at a baseline, which can then help to identify areas of low carbon interventions throughout the life cycle of highways.

Key objectives

- To determine the overall carbon footprint of the NH network
- To suggest low carbon interventions for the highway sector
- To estimate carbon reduction potential of developing 'good-quality' highways vis-à-vis 'poorly-maintained' highways
- To provide recommendations for mainstreaming of strategies and policies and enabling actions for low carbon NH sector

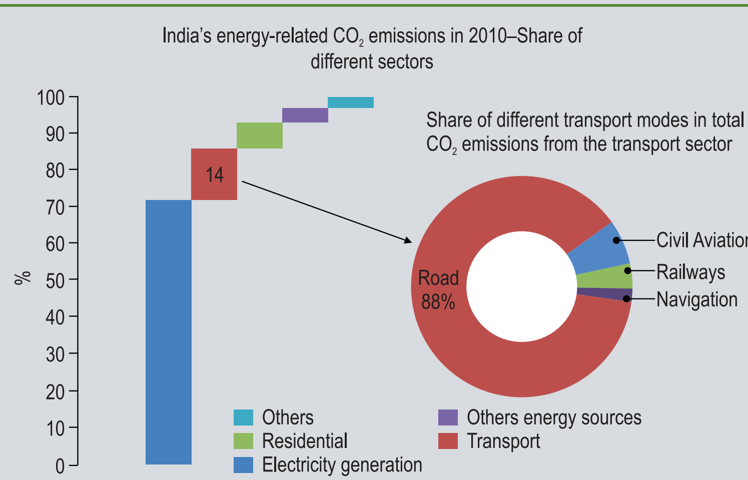

Figure 1: Share of road sector in total energy related CO_2 emissions
Source : Biennial Update Report, 2015)

Carbon footprint of India's National Highways sector

Carbon footprint can be estimated using various methods, such as process-based Life Cycle Analysis (LCA), Environmental Input-Output (EIO), and Hybrid IO-LCA models. For this study, LCA method has been adopted to estimate the carbon footprint of India's NH network. The main activities that have been considered while estimating carbon emissions during the life cycle of a highway are:

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

> Carbon Footprint: "Measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" - (Wiedmann, 2008)

Approach to estimate carbon footprint of NH network

A hybrid approach has been adopted for estimating CO_2 emissions of the NHs sector. The emissions from construction and maintenance related activities on NH network have been estimated by scaling up the emissions determined across representative highway sections. A spreadsheet-based model has been developed as part of the study based on an extensive review of Indian and international methodologies to calculate the emissions during construction and maintenance phases. The operation phase emissions that occur on account of movement of vehicles on highways have been estimated using the traffic estimates for NHs network, as derived from NITI Aayog's India Energy Security Scenario (IESS), 2047 tool. IESS estimates the annual transport demand for India by deploying a bottom-up transport demand activities model; NH traffic estimates and resultant CO_2 emissions have been delivered using this tool. The emissions from these two sources, that is (i) construction and maintenance, and (ii) operations, have been aggregated to arrive at the total emissions from India's NH network (Figure 2).

Construction and maintenance phase emissions

Project-level CO_2 estimates have been used to estimate the carbon footprint of the entire NHs sector. A bottom-up approach for estimation of construction and maintenance emissions necessitated the need to select highway projects/ stretches that could

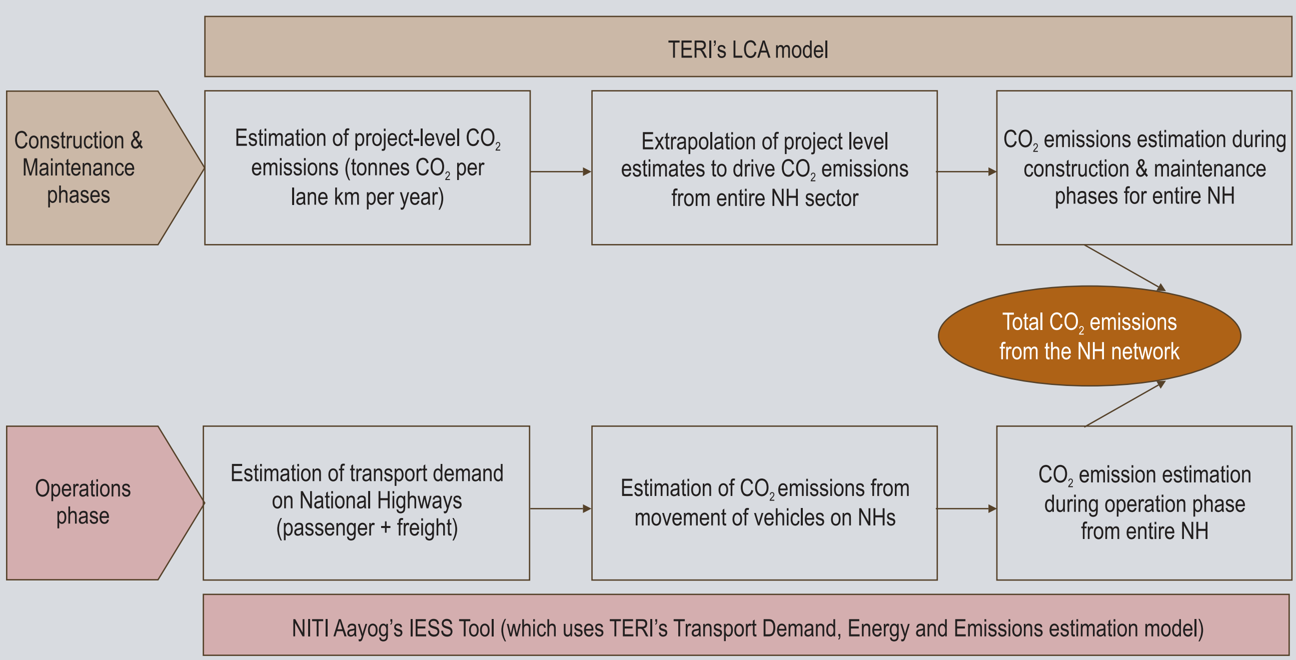

Figure 2: The Big Picture - Modelling approach adopted under this study to estimate total (construction, maintenance and operations) CO_2 emissions from India's NH network

represent the Indian NH network. Eleven such projects, covering around 860 km, were selected in consultation with MoRTH (refer Figure 3 for location of these projects). The emission estimates of these representative highways were then extrapolated to arrive at a national-level CO_2 emission estimate, on account of construction and maintenance activities of NHs. The extrapolation distinguished the CO_2 emission coefficients for different terrain/climatic zones to arrive at the network level CO_2 emissions. It is estimated that the annualized emissions resulting from construction and maintenance related activities on the existing NH network as in 2016 were 18 MT CO_2e.

With an expanding NH network, it is expected that the emissions as a result of construction and maintenance activities would also continue to rise. Keeping in line with the Ministry's objective of adding 20 km of highways every day, it is expected that the NH network in the country would increase from 3.3 lakh lane km in 2016 to 5.7 lakh lane km in 2030 (TERI estimates). Consequently, the annualized emissions from construction and maintenance of the total national highway network in India can be broadly expected to grow from 18 MT CO_2e in 2016 to 31.0 MT CO_2e by 2030.

Operations-related emissions

As stated earlier, the emissions on account of movement of vehicles on NHs have been estimated by first, estimating the traffic on the NHs network in the country, and thereafter

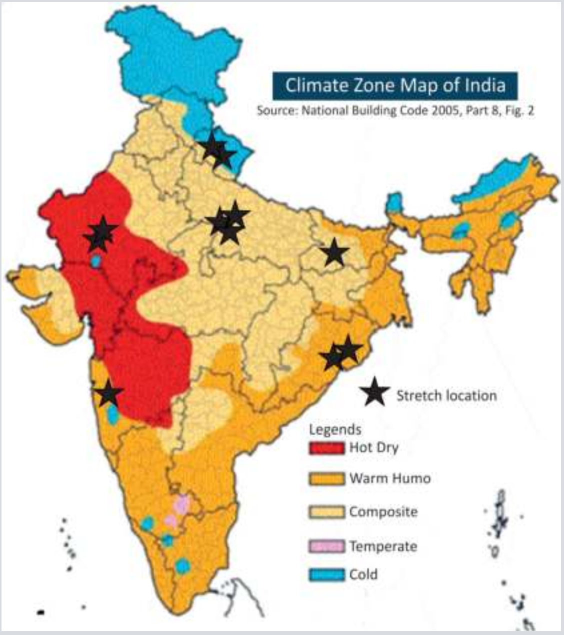

Figure 3: Location of representative highways selected under the study

Box 1: Key findings from the project-level CO_2 emissions estimation

Project level CO_2 emissions were estimated for about 11 projects covering about 860 km (Figure 4). Key findings from project specific carbon footprint (CF) estimates are discussed in the following points.

- CO_2 emissions on account of embodied carbon in materials are in the range of 72% to 95% of the total construction phase emissions for the sample projects – *Emphasizes the need to use low carbon materials in highways' construction and maintenance*
- CO_2 emissions on account of movement of materials from source to site of consumption are in the range of 4% to 26% of the total construction phase emissions for the sample projects – *Emphasizes the need to reduce the lead/ use of efficient modes of transportation*
- Good riding quality leads to higher vehicle efficiencies, lower emissions, and cost savings – *Emphasizes the need to maintain good quality road network* (Box 2)

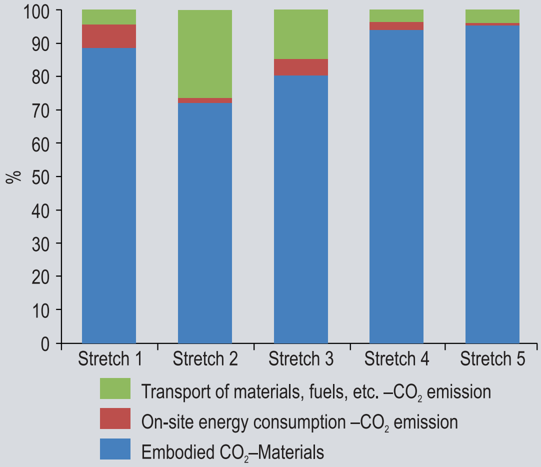

Figure 4: Project-level CO_2 emissions estimates - Share of transport of materials, on-site energy consumption, and embodied CO_2 in materials

Source: TERI Analysis, 2016

estimating the CO_2 emissions on account of movement of this traffic by using NITI Aayog's IESS, 2047 tool.

The traffic estimates for NHs, i.e. passenger km (pkm) and tonne km (tkm), were derived from the IESS 2047 tool, which uses TERI's Transport Demand, Energy and Estimation Model.[1] It is estimated that out of a total of 8,195 billion passenger km and 1,405 billion tonne km of total traffic on Indian roads in

2016–17, 2,458 billion passenger km (30%) and 703 billion tonne km (50%) moved on NHs alone. While there are different categories of vehicles which are plying on the highways, starting from passenger cars to heavy duty vehicles (HDVs), the share of passenger traffic on buses and freight traffic on HDVs appear to dominate the traffic volumes (Figure 5).

These traffic volumes translate into an estimated 105 MT CO_2e emissions from vehicle operations on NHs in 2016. This represents 41% of total transport sector emissions (256 MT) of India in 2016, with the largest share of vehicular emissions on highways coming from HDVs, followed by bus and omni-bus, LCVs, and cars.

Under the business-as-usual scenario, given India's robust economic growth trajectory, the demand for mobility on highways is expected to continue growing. Reflecting this growth, CO_2 emissions from vehicular operations on National Highways are expected to grow to 248 MT by 2030, an increase (CAGR) of 6.3% between 2016 and 2030 (Figure 6). As of 2030, this will represent 37.5% of India's transport sector CO_2 emissions. The source of most of the emissions from vehicular traffic, even in 2030, will continue to be generated due to the operations of HDVs, buses, and omnibuses.

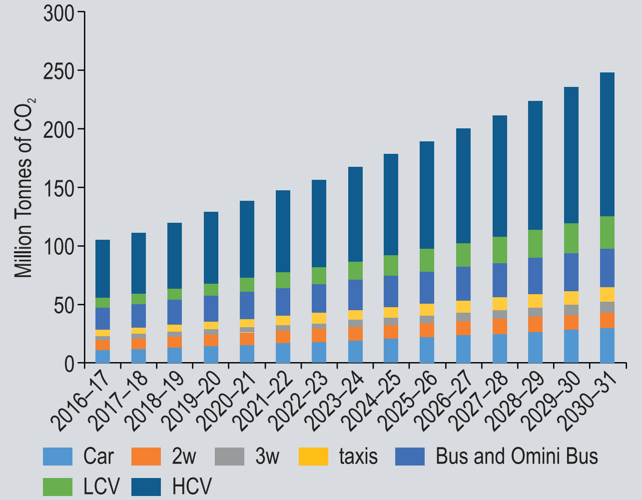

Figure 5: Category-wise CO_2 emissions from NH operations

Source: TERI Analysis, 2016

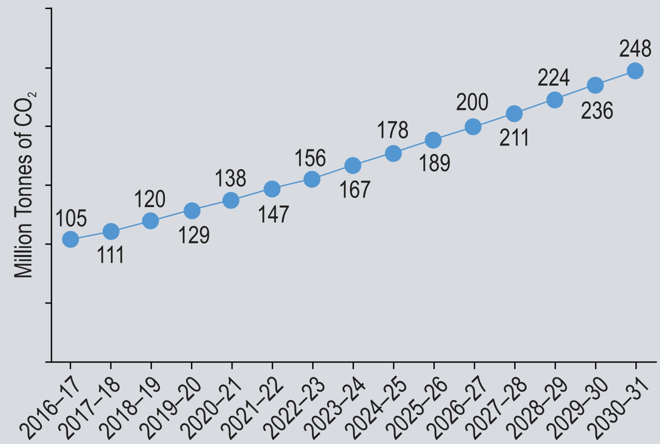

Figure 6: Growth trajectory of CO_2 emissions from vehicular operations on National Highways - BAU scenario

Source: TERI Analysis, 2016

[1] Documents available at http://www.indiaenergy.gov.in/iess/default.php; Model available at http://iess2047.gov.in/pathways/

Total CO_2 emissions from NH sector

Aggregation of the emissions resulting from construction, maintenance (periodic and annual), and operations phases indicates that the operations phase of the highways results in the largest share (~86%) of emissions from highways in India (Figure 7).

Given the growth in the highway network and consequently, the traffic on the highway system, the annualized CO_2 emissions from the highways are expected to increase to 278 MT by 2030 (Figure 8). With this 2.3 times growth in emissions, the need for carbon reduction from the NHs acquires utmost importance in order to meet India's commitment of reducing its CO_2 emissions.

Annualized CO_2 emissions from National Highways sector expected to increase from 123 MT in 2016-17 to 278 MT by 2030-31

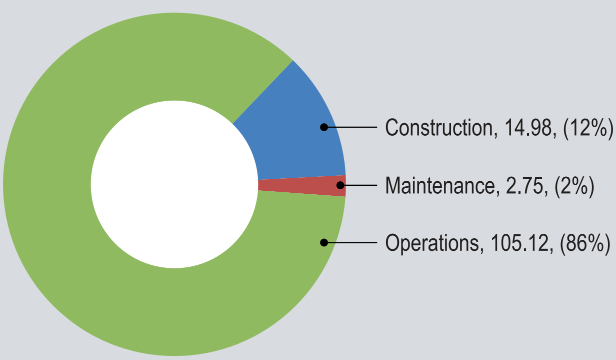

Figure 7: Emissions and share of construction, operations, and maintenance from India's NHs sector in 2016 (million tonnes, %)

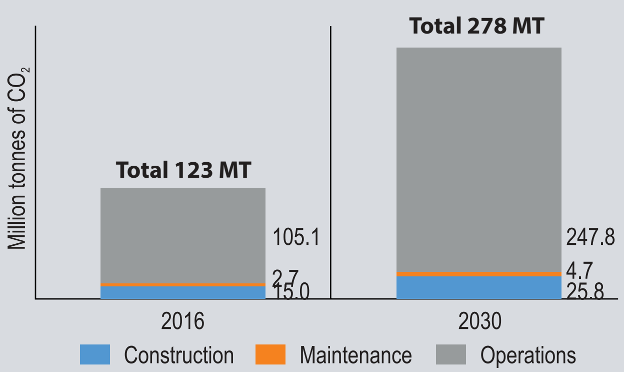

Figure 8: CO_2 emissions on account of construction, operation, and maintenance of NHs in India during 2016 and 2030

Strategies for developing low-carbon NHs

The report suggests potential measures that can be implemented to reduce carbon emissions from the NHs sector. Given the high share of operations phase in

Box 2: Good quality vs Bad quality highways – Cost and emissions savings

Orai-Barah section of NH-24 (62.8 km) in Uttar Pradesh was selected as a case study to demonstrate the effect of maintenance on emissions and cost savings on account of reduced roughness index. Construction work was completed in July 2009 and first periodic maintenance was completed in September 2016 at a cost of Rs 69.2 crore. The roughness index was calculated both before and after the periodic maintenance activity, which was sourced from the developer (Orai Barah Infrastructure Ltd). Post maintenance, roughness index value improved from an average of 2.86 metre/km to 1.815 metre/km. Vehicular fuel efficiency improvements as a result of this improved roughness index were estimated; estimations indicate total fuel cost savings post periodic maintenance to be about Rs 2.03 crore during the first year.

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

Fuel	Fuel consumption before periodic maintenance (kl)	Fuel consumption after periodic maintenance (kl)	Fuel savings (kl)	Cost savings (Rs lakh)
Petrol	592	586	6	3.78
Diesel	23,415	23,022	392	199.42
Total	24,007	23,609	398	203.20

Note: Average yearly price of petrol taken at Rs 62.62 per litre and diesel at Rs 50.86 per litres during 2016 (IOCL); kl: kilo-litres
Source: TERI Analysis, 2016

Cost savings over 5-year period: Between the first and second periodic maintenance of the Orai–Barah section, it is estimated that a total of Rs 6.6 crore is saved on account of better riding quality during the first three years and a loss of Rs 6.2 crore on account of increase in roughness index during fourth and fifth years.[2] The net benefit on account of periodic maintenance stands at a marginal amount of about Rs 40 lakhs under this project.

CO_2 emissions savings over 5-year period: A total of 3,400 tonnes of CO_2 is estimated to be saved during the first three years of periodic maintenance, while 2,800 tonnes of CO_2 is estimated to be emitted during the fourth and fifth years due to the deterioration effect leading to net emission savings of 600 tonnes over a 5-year period.

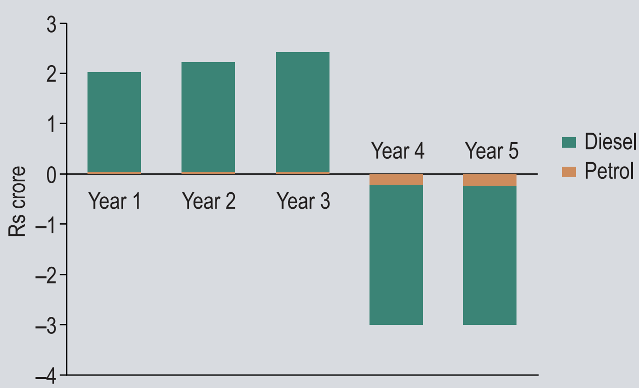

Figure 9: Projected fuel cost savings/loss on account of improved/deteriorated surface quality post periodic maintenance
Source: TERI Analysis, 2016

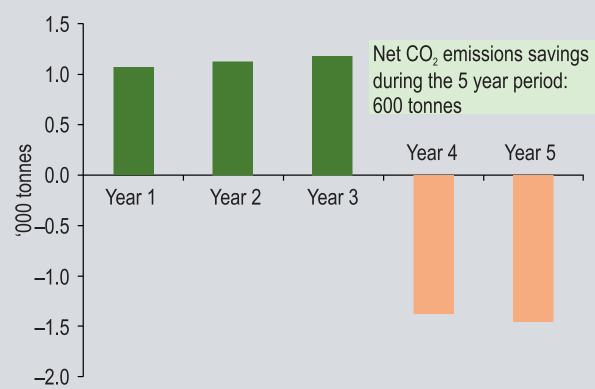

Figure 10: Projected CO_2 emissions savings/loss on account of improved/deteriorated surface quality post periodic maintenance
Source: TERI Analysis, 2016

[2] Basic assumptions are that traffic on stretch grew at 5% per year, fuel price at 4% per year, and deterioration factor kicks in from the fourth year onwards post periodic maintenance.

carbon emissions (nearly 90%), specific interventions to reduce the same have been suggested along with measures to make NH construction and maintenance low-carbon.

Interventions to reduce operations phase emissions

The significantly high share of CO_2 emissions from the operations phase of NHs necessitates exploration of strategies that help in reducing the emissions from this phase. Given the large volume of traffic currently operating on highways, measures that could reduce the energy intensity levels of these modes would be instrumental in reducing the overall volumes of emissions from highways. The following section suggests the key interventions that could be implemented to reduce CO_2 emissions from vehicular operations on NHs (Figure 11).

Increased share of energy efficient modes of transport

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

It is estimated that an increase in rail share in passenger movement by 13% and in freight movement by 17%, can result in CO_2 emissions reduction of about 12%.

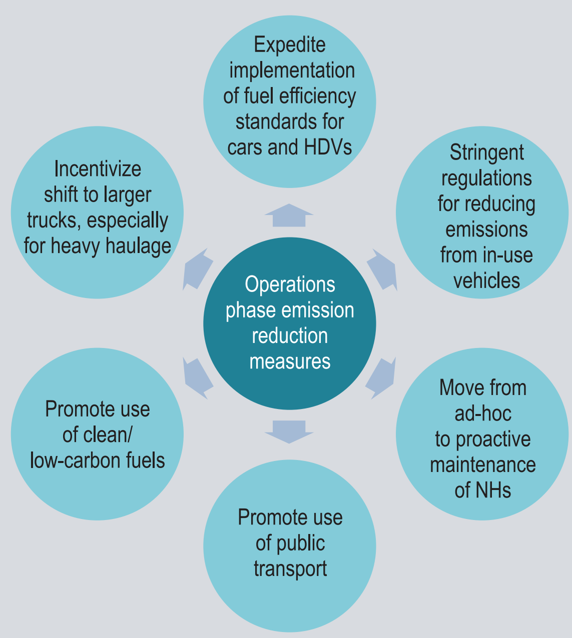

Figure 11: Interventions to reduce CO_2 emissions from vehicular operations on NHs

3 https://www.beeindia.gov.in/sites/default/files/ctools/Notification%20 23.4.2015.pdf

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

Expedite implementation of fuel efficiency standards for cars and HDVs: The GoI has notified the fuel efficiency standards for passenger cars[3] and HDVs.[4] Implementation of fuel efficiency standards, especially for HDVs, which account for the highest share in emissions during operations phase, will go a long way towards emission reduction from India's NH sector. As per TERI estimates, in a scenario where fuel efficiency norms formulated by the GoI lead to a 20% improvement in fuel efficiency levels for both cars and heavy-duty vehicles starting 2017, the estimated reduction in annual highway emissions from traffic operations is at about 13% in 2030. It is suggested that the implementation of fuel efficiency standards should be expedited and monitored for effective results.

Establish stringent regulations for reducing emissions from in-use vehicles: The GoI needs to establish and implement stringent norms focussing on emission reduction on account of in-use vehicles. Under this, the two focus areas of the government are described as follows:

- *Improve the inspection and maintenance (I&M) system for on-road vehicles*: Poorly maintained vehicles are a major source of emissions from the transport sector. The practice of scheduled maintenance of commercial vehicles is almost missing or, at best, taken up in the unorganized sector (ex-OEMs). It is recommended that a robust inspection and maintenance system for on-road vehicles, especially commercial vehicles, is implemented to check emissions on account of non-maintenance of vehicles.

- *Notify a policy for scrapping of old vehicles*: Old/inefficient vehicles are also a huge source of carbon emissions and need to be phased out in a planned manner. In May 2016, MoRTH came out with a concept note on Voluntary Vehicle Fleet Modernization Programme to encourage vehicle owners to replace their old vehicles with new ones. It is recommended that the programme should be implemented as early as possible and the replacement/scrapping of old vehicles be made mandatory instead of voluntary.

Move from ad-hoc maintenance practice to proactive maintenance of NHs, especially for NHs developed through the EPC mode: This is important, especially for projects developed on the basis of engineering, procurement, and construction (EPC), as NHs developed on the PPP basis, have an in-built maintenance clause within the contract. In this regard, the two significant focus areas for the government are described as follows:

- *Ensure adequate provision of funds for maintenance*: Adequate allocation of funds towards maintenance activities, as prescribed under the Report of the Committee on Norms for Maintenance of Roads in India, is required. There is a need to revisit the norms/formulae to estimate the maintenance fund requirement based on traffic plying on NHs; the norms were last formulated by the committee titled 'The Norms for Maintenance of Roads, 2001'. It is recommended that adequate allocation be made towards NH maintenance so that there is no delay in maintenance on account of constraint of funds.
- *Promote innovative and advanced maintenance practices*: Use of some of the advanced maintenance techniques/equipment, such as slurry seal machines, combined bitumen sprayer and chip spreader, cold/hot recycling methods, etc., needs to be encouraged to improve maintenance practices and their outcomes.

Incentivize shift to larger trucks (engine size >9 litres), especially for heavy haulage: Shifting to larger trucks offers significant potential in reducing energy consumption and CO_2 emissions levels by making their operations efficient. It is recommended that for these larger trucks, the engine size of >9 litres, especially for heavy haulage (>25 tonnes), is considered to keep an optimum engine-to-weight ratio and, is therefore, more efficient. Currently, with low engine-to-weight ratios in the Indian HDV segment, there is an adverse impact on efficiency and the speed of trucks.

Promote use of clean/low-carbon fuels, such as electricity and biofuels: This will involve a two-pronged strategy—(i) Providing infrastructure along NHs for supporting use of alternate fuels (charging stations, pumps dispensing greener fuel/biofuels, etc.); and (ii) Promoting adoption of alternate fuels/vehicles technologies through demand incentives, consumer awareness, etc.

Promote use of public transport: Modes of public transport, such as buses, are significantly less emission-intensive than vehicles, such as cars and taxis. A dedicated effort towards shifting passenger mobility from cars/taxis to buses could help mitigate emissions resulting on NHs in India. Efforts to increase the service quality, reliability, and safety of State Road Transport Undertakings (SRTUs)/ State Road Transport Corporation (SRTC) buses could potentially shift some of the existing passenger traffic from passenger cars to buses.

Interventions to reduce construction and maintenance phase emissions

Even though construction and maintenance phases account for a low share of about 14% of the total carbon emissions from the NHs sector, India also needs to focus on reducing emissions during these phases by adopting clean/low-carbon practices/technologies/ materials. The potential interventions that can help reduce the overall CO_2 emissions from NH sector are discussed in the following section (Figure 12).

Institutionalize a Carbon Rating System for NHs: Carbon emissions estimation during the construction and maintenance phases should be done at the Detailed Project Report (DPR) stage to calculate the life cycle CO_2 emissions for all the NH stretches. While the initiative will help identify project specific low-carbon interventions, it will also help generate a robust database of CO_2 emissions from different stretches in different terrains/climate zones. This database can help initiate a 'Carbon Rating System', which could help quantify the performance of the NH projects on a carbon footprint scale. To encourage the adoption of low-carbon interventions in project design, MoRTH could provide incentives, in terms of awards or monetary incentives, to recognize low-carbon initiatives/low-carbon NH projects through this carbon rating system. With regard to institutionalization, a pool of experts for evaluating carbon emissions estimated and low-carbon interventions adopted in DPRs could be housed in MoRTH under an appropriate department or the unit proposed in Component II of the study (Figure 14). The unit should be made responsible to push for low-carbon interventions as well as creation and maintenance of data.

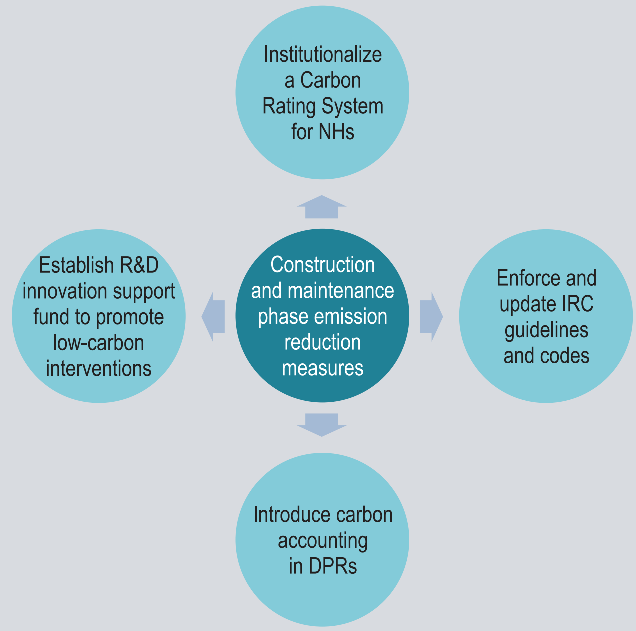

Figure 12: Interventions to reduce CO_2 emissions from construction and maintenance of NHs

Enforce and update IRC guidelines and codes to promote adoption of low-carbon construction/maintenance materials and techniques: MoRTH has undertaken several measures, including constitution of committees for reduction of carbon footprint and material specific interventions, to promote the use of green/alternate materials. The key, however, is actual implementation or use of these materials on ground. There is a need to generate awareness about low-carbon materials and methods, which are already included in IRC guidelines and codes. It is also important to undertake demonstration projects so as to establish the viability of low-carbon methods and materials. For materials not covered under any IRC codes/guidelines, it is recommended to undertake research and development as well as pilot projects.

Introduce carbon accounting in DPRs: It is suggested that certain amendments/additions are made in the DPR document to introduce carbon accounting and fast track the adoption of green/alternate materials during the construction and maintenance of NHs.

- Carbon accounting of construction/maintenance activities should be made mandatory at the DPR preparation stage.
- Life cycle analysis should be made mandatory in line with the General Financial Rule 2017 (Clause 136), Department of Expenditure, 2017.[5]
- Life cycle CO_2 emissions and costs should be compared for conventional and alternate designs.

Establish R&D innovation support fund to promote low-carbon materials and methods: This fund should be used to support the incremental cost on account of using alternate/green materials.

It is recommended that the above discussed interventions should be considered for implementation to promote low-carbon growth of NHs in India.

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[5] http://mof.gov.in/the_ministry/dept_expenditure/GFRS/GFR2017.pdf

Component II
Enhancing Climate Resilience of National Highways in India

Introduction

The changing climate, manifested through weather anomalies and extreme weather events, is one of the foremost emerging global challenges. The impacts of climate change, such as rising temperatures, sea level rise, and increase in climate induced extreme events, all pose direct physical risks to infrastructure and assets and threaten vital infrastructure, such as roads, bridges, rails, etc. During the occurrence of extreme climatic events, such as cyclones, extreme rainfall, etc., roads are mostly inundated, trees uprooted, and collapse of electric poles, thus, blocking connectivity, affecting traffic, and disrupting evacuation operations. Generally, a significant proportion of the economic loss of an extreme weather event is attributed to the direct physical loss and damage to infrastructure which includes roads, highways, and bridges.

Spread over 33 lakh km, India's road network is the second largest in the world. Of this, the National Highways constitute about 2% of the road network in the country while carrying about 40% of the total road traffic (NHAI 2014). They provide transit to freight, cargo, tourists, and locals, and serve as exodus routes when citizens need to evacuate during threat of extreme events, such as cyclone threats and mandatory evacuations. Therefore, while all roads need to be climate resilient it is more important to ensure that National Highways are climate resilient. In order to minimize the disruptions and economic cost implications due to extreme climate events, it is required that highways be planned to adapt to the changing climate. It is significant to note that National Highways are significant with respect to economic activities and carrying out evacuation/ rescue plans and vulnerable insofar as extreme climate events are concerned. Therefore, the need for investing in enhancing resilience of highways is pronounced. This clearly calls for the need of an approach for vulnerability assessment (VA) of National Highways, which can be used to identify vulnerable highway stretches and sections for prioritizing investments in making roads climate resilient.

Climate Vulnerability Assessment of National Highways

TERI, through this study, has developed a methodology to conduct climate VA of National Highways in India. To develop this methodology, a review of globally accepted methodologies used for conducting climate vulnerability and risk assessment of infrastructure assets has been carried out. The key takeaways from the review of relevant methodologies have been contextualized and adopted for developing a new and customized methodology for climate VA of National Highways in India (Figure 13). This methodology for VA can be used as a step-by-step guide for understanding climate change risks and identifying adaptation options for roads sector, both at the network and stretch levels in India. Roads connected with one other form a network and every road is treated like a stretch, for instance NH 5 Shimla to Moorang. Thus, the National Highways constitute a network. While networks in different regions, such as hilly, coastal, etc., face different climatic risks, different stretches, within each network, could face climatic risks to a different degree.

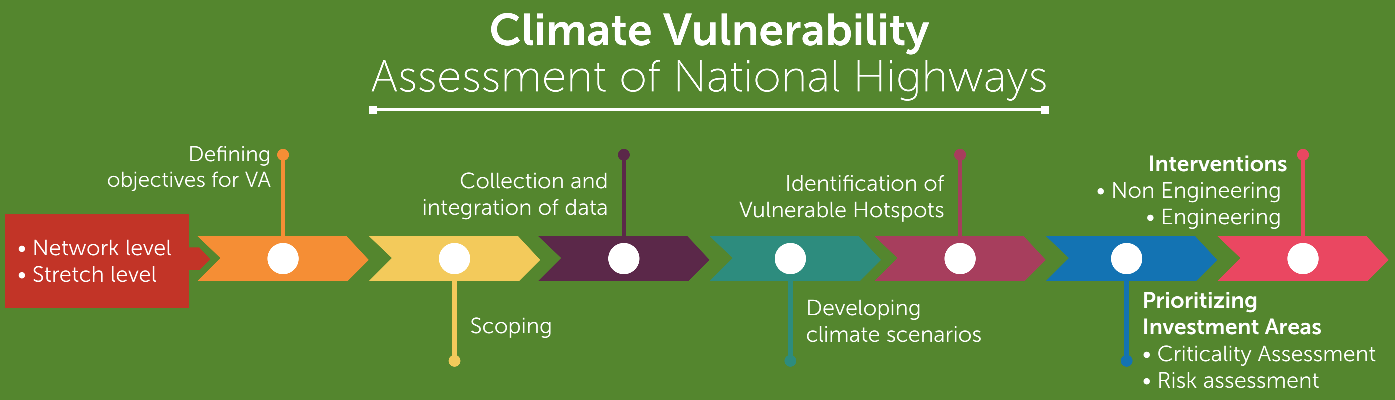


Figure 13: TERI's proposed Methodology for Vulnerability Assessment of National Highways

As is clear from Figure 1, the objective of conducting the vulnerability assessment must be established. Once the objective has been established, the scope must be defined, for instance whether the assessment should be restricted to the road or whether it should include other surrounding physical infrastructure. Defining the scope would also include identifying data parameters and analytical tools and techniques (Box 3). To identify vulnerable highway stretches/sections, the data with respect to past climate, such as rainfall and past climate-induced extreme events and disasters (cyclones, landslides, etc.) and information related to highways (pavement conditions, safety infrastructure, drainage, topography, etc.) is mapped over the selected study area. This provides the exposure profile of the selected area. The future climate data (developed through climate modelling or extracted from a previous study) is then overlaid onto the exposure profile. This finally results in the

Box 3: Scoping Parameters

Scope	Parameters
Delineation of geographical limits	Key settlements/nodes, infrastructure assets, low lying areas, transport terminals, and economic hubs
Identification of key issues and parameters	Climate stresses (trends of key climate parameters, past extreme climate events), non-climatic stresses (terrain, drainage, and material and construction technique of highway)
Identification of sources of data and local knowledge	Based on key issues and parameters
Identification of analytical tools and techniques	GIS mapping, climate and SLR projection modelling exercise

identification of vulnerable highway stretches and sections. At the network level, once the vulnerable highway networks and stretches have been identified, a 'Criticality Assessment' needs to be conducted to identify and prioritize the 'critical' highway stretches for investments in resilience building. The critical highway stretches can be identified based on certain indicative parameters (Box 4).

In this study, the methodology has been applied on the entire National Highway network and on two selected stretches (hilly and coastal). At the network level, in order to assess the overall climate vulnerability of the National Highway network, cyclone, wind, and earthquake hazards, and future climate scenario (percentage changes in future extreme rainfall) have been overlaid. On the basis of this, the final vulnerability map of India has been drawn (Map 1) which shows the different regions susceptible to different climate risks. This map clearly brings out that around 37% of the National Highways, that is, highway networks falling in the Himalayan region, North-Eastern states, east coast of India and the coastline of Gujarat, Maharashtra, and Goa on the west coast are found to be highly vulnerable.

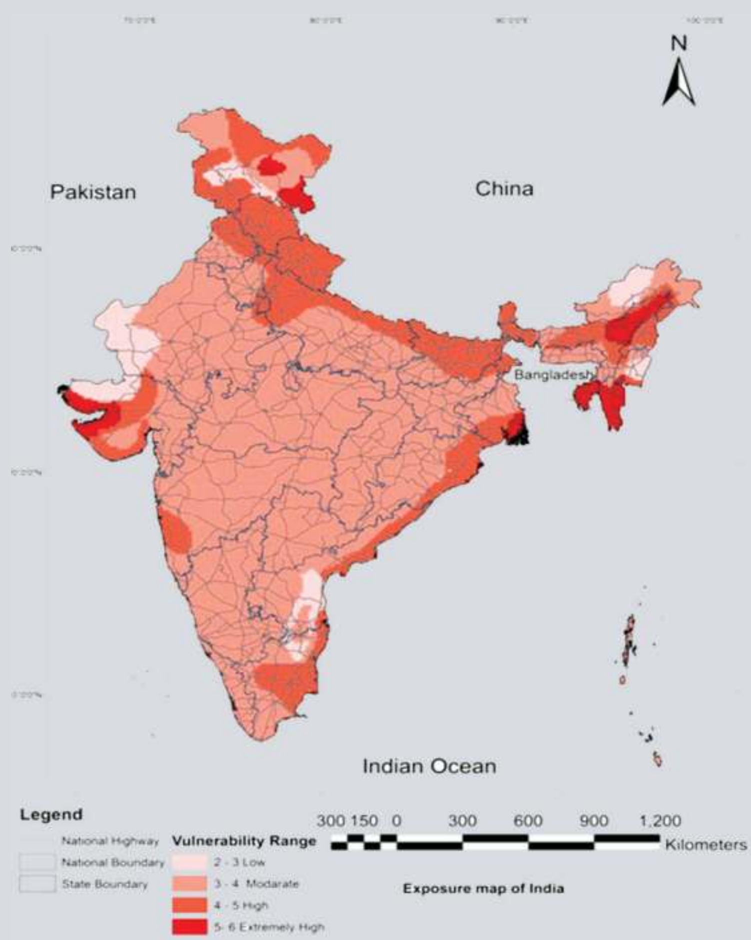
Box 4: Indicative checklist for criticality assessment parameters

Economic Importance—Intermodal connectivity–provides access to airport, port or rail; Connects Industries/Power Plants; Serves economic centres- SEZ/route for a primary economic activity; Connects major settlements

Operational Characteristics—Functional classification, Usage- Annual Average daily traffic

Component of the National Defence System, for instance, National Highways connecting border roads and critical national defence areas

Health and Safety—Part of disaster relief and recovery plan, for instance, identify evacuation route or key connection during emergency situations



Map 1: Vulnerability Mapping for National Highways in India

Source: TERI Analysis, 2016

Interventions for Building Climate Resilient Highways

Based on the outcomes of the vulnerability assessments, engineering and non-engineering interventions to address the vulnerabilities of the National Highways in India have been recommended.

Engineering Interventions

Table 1 describes region-wise engineering interventions that can be adopted in various regions across India, namely, hilly, coastal, desert, plains, etc., in line with the impacts of climate change on National Highways.

Table 1: Engineering Interventions

Region	Climate stressors	Impact on highway elements and infrastructure	Engineering Interventions
Desert, Plains, Coastal Areas	High Temperatures	• Softening of pavement resulting in rutting and shoving • Buckling, heaving at joints of the pavements • Cracking of pavements, thus rendering it more susceptible to rains and potholes, and also affecting structural stability	• Use of road surface grids, such as glass grids, composite geo grids, steel meshes, etc., for structural reinforcement of asphalt pavements to provide lateral restraint, hence improve resistance to rutting and shoving • Use of paving fabrics as a moisture barrier to reduce cracking • Use of appropriate asphalts and asphalt binders to prevent cracking of pavements • Microsurfacing technology (cold mix asphalt, defined aggregate and bitumen emulsion), helps in preserving pavement strength and preventing cracks • Use of crack sealing materials, such as asphalt emulsion slurry seal, asphalt cements and fiberized asphalt, self-levelling silicone, etc., to prevent the intrusion of water through the crack • Patching—Process of repairing potholes to prevent water seepage materials for patching include hot mix asphalt, asphalt emulsion mixes, stockpile patching mixes, and proprietary patching mixes
Coastal and Hilly areas and Plains	Intense rainfall/ Extreme Precipitation events	• Increase of pore pressure in pavement layers of roads resulting in revelling of pavement surface	• Use of water soluble, UV, and heat stable chemical soil modifier to reduce swelling. However, the longevity of this treatment is yet to be established
		• Erosion and subsidence of paved roads	• Increased soil stabilization through compaction, drainage, mechanical stabilization, and chemical stabilization to increase soil strength and the resistance of soil to water
			• Using natural or synthetic erosion control mat for prevention of erosion of side slopes of the pavement section
		• Infiltration of rainwater into the layers below and thus, damaging the structural stability of the road	• Geo-composite drainage systems for both drainage under pavements and drainage behind retaining walls, that is, fin drains, to improve drainage capacity • Provision of impermeable interlayer, that is, Paving fabrics which works as a moisture barrier to prevent cracking
		• Water overtopping and wash away of road pavement	• Proper geometric design (slope, camber) and provision of side drains of required capacity
		• Reduced capacity of drainage system due to debris accumulation, sedimentation, erosion, scour piping and conduit structural damage, and hence, flooding of roads	• Annual and periodic maintenance of drainage, particularly in pre monsoon and monsoon period. • Provision of causeways and vented causeways to cater to HFLs and flash floods
	Storms/dust storms and stronger winds	• Clogging of roadside drains due to debris from storm	• Annual and periodic maintenance of drainage

Region	Climate stressors	Impact on highway elements and infrastructure	Engineering Interventions
Hills	Intense rainfall/ Extreme Precipitation events	• Risk of landslides, rock falls, and floods from runoff • Slope failures	• Protection measures—Containing or directing the rocks to ditch or other catching structures, such as Geo-nets/ Drapery systems, wire meshes, rock bolts, berms and benching, rockfall ditches and trenches, rock sheds, and tunnels and rockfall barriers and embankments (gabion walls, structural walls, etc.) • Protection measures—Use of erosion control mats/blankets and other bio-engineering measures, such as hydro seeding methods, mulching, etc. • Retention Measures—Use of slope reinforcement with rock bolts, soil nailing, mesh with anchors and grouting, etc. • Prevention measures—Modification of slope geometry by removal of material from the upper areas, reduction of slope angle and trimming of loose surface material, reinforcing slope face, benching, etc. • Prevention Measure—Improving slope stability through the installation of drainage systems, which most often consist of horizontal weep
Coastal	Sea level rise, cyclones, and storm surges	• Coastal road flooding and subsequent damages • Erosion of coastal road base	• Coastal armouring, such as building sea walls, breakwater, groynes, storm surge barriers, etc. • Use of geo tubes and geo containers for storm surge protection, also for breakwaters • Greening of coastal belt for cyclone protection • Embankment slope vegetation to protect the highway from coastal flooding and erosion
		• Electric poles, trees falling on road	• Underground cabling of electricity and other communication lines • Use of spun concrete electric poles instead of the normal electric poles in order to better withstand extreme winds
Plains, Hills	Extreme Temperatures and Permafrost	• Changes in freeze and thaw cycle making road surfaces more susceptible to potholes and rutting • Extreme high temperatures resulting in cracking of pavements	• Use of precautionary measures as per IS 7861- Part 1(hot weather) and Part 2 (cold weather) for extreme weather concreting

Sources: Nanotechnology for water resistant soil bases, 2017; New technology for dust control, erosion resistance and water resistance, 2017; Zydex Road Solutions, 2017; Gujar, *et al*. (2013); Bobrowsky, 2008; Roychowdhury, 2015; Bureau of Indian Standards, 1999; Indian Road Congress, 1998, 2011, 2017; stakeholder interactions 2017;

Non-Engineering Interventions

To mainstream climate resilience in the National Highways sector, it is important to strengthen the inter-linkage of planning, design, construction, and maintenance of roads and climate resilience measures at a policy level. Non-engineering interventions to mainstream climate resilience in the highways sector will need a multi-pronged approach through the following measures:

- **Mainstreaming in planning and approval processes**—Vulnerability assessment at the stretch level should be included in the terms of reference (TOR) by the project proponents for Detailed Project Report (DPR) consultants and be made mandatory in the feasibility study/DPR.
- **Facilitating the updating of IRC codes, regulations, formulating region-wise road construction and maintenance guidelines in the context of the changing climate.**
- **Inter-departmental coordination** at national and sub-national levels, especially with respect to information sharing and policy making. These will include coordination between Indian Meteorological Department (IMD), Ministry of Road Transport and Highways (MoRTH), National Highways Authority of India (NHAI), state public works departments (PWDs), disaster management department, etc.
- **Data Management**—Maintain data on climate change and extreme events that impact National Highways.
- **Research and Capacity Development** to explore alternative construction materials and technologies and also bridge knowledge and capacity gaps of highway engineers, practitioners, and consultants.

To this end, it is recommended that a dedicated climate change unit be institutionalized in the MoRTH. The unit will act as the nodal point for climate change concerns in NH sector, such as coordinating research and development, data management and information sharing, and formulation and enforcement of codes and guidelines for resilience building of NHs. It is also recommended to empanel a set of consultants/expert agencies to support the unit in conducting the Vulnerability Assessment studies. The unit will also function as a National Data Centre and maintain data on climate change and extreme events impacting NHs and also future climate data.

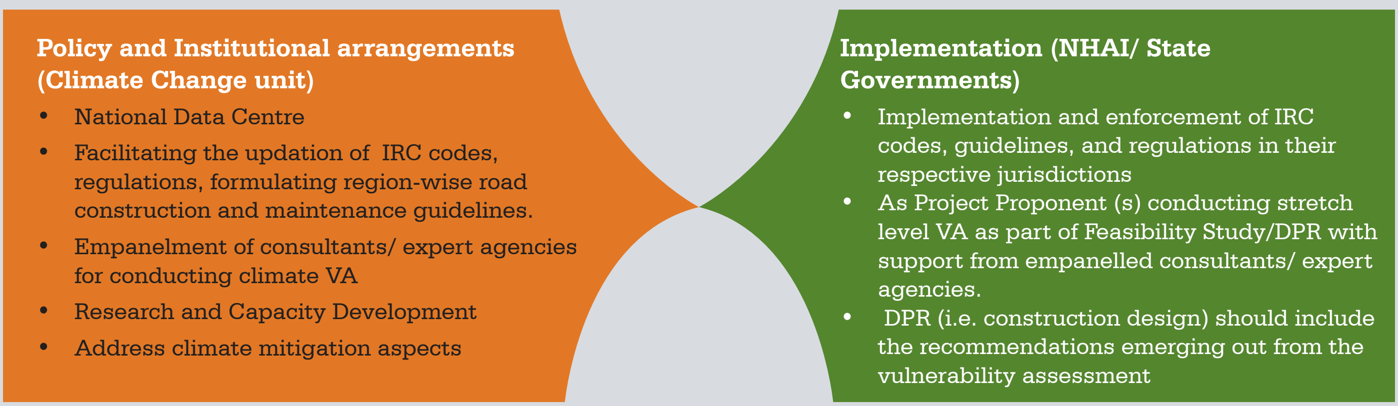


Figure14: Mainstreaming of proposed institutional changes

All the interventions have been recommended for National Highways as this study's focus is on NHs. However, it is suggested that MoRTH may recommend these interventions, for resilience building of all roads and highways in India, to other relevant agencies at national, state and city level as well, apart from NHAI.

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New Delhi: The Energy and Resources Institute.

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