DECARBONIZATION OF TRANSPORT SECTOR IN INDIA: PRESENT STATUS AND FUTURE PATHWAYS

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CONTENTS

EXECUTIVE SUMMARY

Globally transport accounts for 23% of the energy-related CO_2 that feeds global warming. In the future, carbon emissions from the transport sector are estimated to grow faster than most other sectors. Decarbonization of transport is now being taken up seriously by policymakers and is an essential step to achieve global climate change mitigation targets.

The transport sector in India is presently powered by carbon-intensive gasoline-based fuels. Some of the present trends are highlighted below:

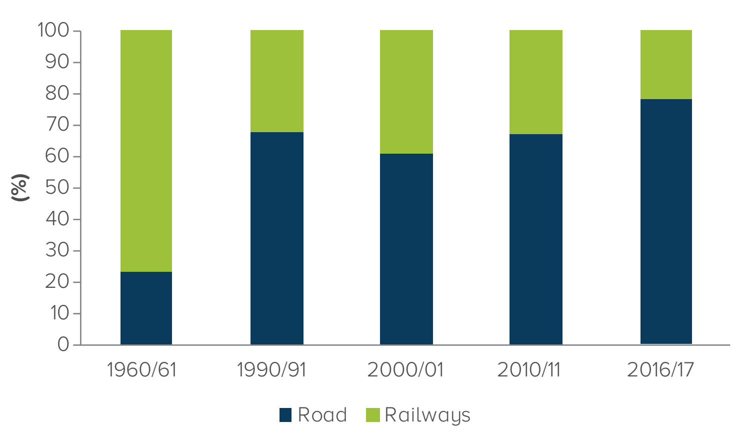
– Around 70% of freight movement and 90% of passenger movement can be attributed to the road sector alone.

– The transport sector accounts for 70% and 99% of the total high-speed diesel (HSD) and petrol consumption in the country, respectively

– Between 2008 and 2018, estimated energy consumption from transport has increased by 22%—a very large increase.

– India's Third Biennial Report (2021) estimates that 274 million tonnes of annual CO_2 equivalent emissions could be attributed to the transport sector in 2016. This represents about 11% of the net emissions from the whole economy

– Emissions remain well below the highest emitters with similar populations, such as China and the United States. This is down to the much lower motorization rate at present.



Source: *Ministry of Road Transport and Highways (MoRTH) and Railway Board*

Study Objectives

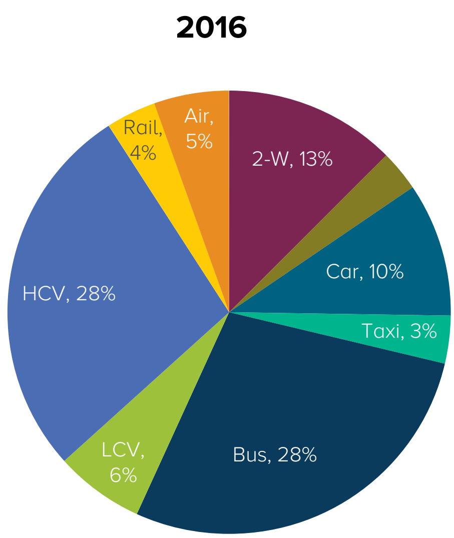
The transport sector in India must grow to enable economic development while decoupling from its negative environmental externalities. Several different strategies already exist within the avoid, shift, and improve framework. This study aims to better understand the potential of present decarbonization policies in India to reduce emissions by 2050 and identify further actions to enable deeper decarbonization. The specific objectives are listed below

- Projection of future transport trends across road, rail and air till 2050
- Assess present decarbonization policies
- Assess emission reduction potential and infrastructure requirements of expected pathways based on present policies
- Identify further actions for accelerating decarbonization in the transport sector

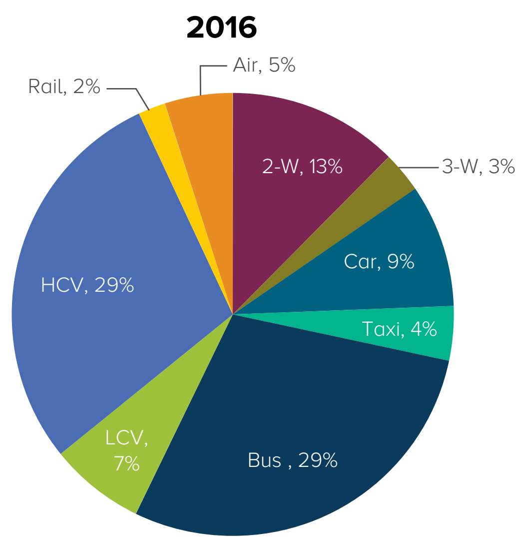
Projected future trends in a business-as-usual (BAU) scenario

A bottom-up modelling exercise was carried out to project the future trends from the transport sector in India up to 2050. Some of the key findings under business-as-usual assumptions are stated below:

- Annual passenger ton-kilometers estimated to increase 3-fold between 2016 and 2050:
  - Motorization rate estimated to increase 3-fold.
  - The share of private cars in total passenger demand increases at the expense of buses and mass transit.
- Annual freight ton-kilometers estimated to increase 7-fold between 2016 and 2050:
  - Faster growth than the passenger segment, driven by continued GDP growth and lower base.
  - Share of rail continues to decline. Freight activity attributable to M/HCVs increases from 58% in 2016 to 66% by 2050.
- The overall energy demand from transport increases more than 4-fold between 2016 and 2050:
  - The major share of energy consumption comes from HCVs and buses at all time points, both depend heavily on diesel.
  - The share of diesel and gasoline in the BAU scenario remains as high as 82% even in 2050—decreasing only slightly from 90% in 2016.
- Annual emissions from transport are estimated to increase 4-fold by 2050 to 1164 million tonnes. This increase is much higher than most other sectors and would increase the share of transport in total emissions to 19%.



Segment-wise share of energy consumption



Segment-wise share of CO_2 emissions

Decarbonization Policies

In the last few decades, policymakers have largely focussed on expanding transport infrastructure to meet skyrocketing demand. The main strategy has been augmenting infrastructure for all transport modes. The road sector has seen the largest outlay, leading to massive growth in road connectivity. An estimated 44% of all transport funds are allocated for road construction alone (Sharma and Rajput 2017). The development of urban transport infrastructure has also been a key area of focus. The National Urban Transport Policy, JNNURM, Smart city project, and AMRUT are some recent urban policies with a focus on transport. While these policies have overarching goals of promoting holistic and integrated transport, implemented projects have largely focussed on improving road infrastructure. The bulk of expenditure by city governments on transport infrastructure still focuses on building new roads, bridges, and flyovers (Shakti 2017).

In the past, the policy focus has been on enabling mobility to meet the goals of economic growth and social development. With the multi-fold increase in transport activity, recent environmental issues associated with carbon emissions and air pollution have come to the fore. Policy actions have also adapted to these needs and policies related to decarbonization have come up in the recent past. Significant efforts have already been undertaken by the State and Central Governments for implementing decarbonization policies in the country. Some of the most prominent ones are listed in the table below.

		Policy Instruments		
		Market-based	Regulations	Infrastructure based
Policy Approach	Improve	➢ Faster Adoption and Manufacturing of Electric Vehicles (FAME) Scheme ➢ State-level EV policies ➢ Scrappage policy ➢ Green tax	➢ Auto-fuel policy, 2015 ➢ National Policy on Biofuels, 2018 ➢ CAFÉ-1 ➢ CAFÉ-2 (upcoming) ➢ Fuel efficiency standards for M/HDVs ➢ Acceptance of hydrogen and LNG as automotive fuel	➢ National Electric Mobility Mission Plan ➢ National Hydrogen Mission ➢ Electrification of railway operations ➢ CNG program
	Shift			➢ National Rail Plan, 2020 ➢ Waterways Act, 2016 ➢ Higher budget allocation for buses and metros ➢ JNNURM scheme
	Avoid/ Reduce			➢ National Transit Oriented Development (TOD) Policy ➢ Urban Green Mobility Fund ➢ Smart Cities Mission

There is a real positivity and acceptance of the need for a clean carbon-free transport sector from all stakeholders. The section below lists out some of the positive developments while also addressing some of the gaps as identified from the study.

Positive Developments

- Consistently high public investment in roads and bridges has led to the rapid expansion of the road network and increased rural connectivity.
- Increased focus on enabling electric mobility with policy push through purchase and manufacturing initiatives at both Central and State levels.
- Promising adoption of electric vehicles in some segments such as two-wheelers and three-wheelers.
- A dynamic automobile manufacturing industry actively focussed on partnering in a shift to electric mobility.
- Increased proliferation of metro systems in urban areas providing more alternatives to private vehicles.
- Significant focus on improved vehicle efficiency through the introduction of ambitious fuel efficiency norms.
- Early recognition of the role of alternative fuels such as natural gas and hydrogen and focus on identifying a clear roadmap for enabling these fuels.

- An extensive railway system is poised to play a key role in decarbonization with an aim to become a net-zero system by 2030.
- Adoption of economic instruments such as scrappage policy and green taxes to incentivize a shift to newer efficient vehicles.
- Successful deployment of CNG vehicles in some cities for commercial operations

Key Gaps and Issues

- Coordinated policy planning is lacking, too many government agencies are involved in transport planning.
- Electrification is most relevant for limited road transport segments, these include two-wheeler, three-wheeler segment, passenger cars, light commercial vehicles, and urban buses.
- Hard-to-abate road segments, long-distance buses, and heavy-duty vehicles account for more than 40% of the total energy consumption, deep decarbonization depends on finding solutions for these segments.
- Decreasing share of rail in freight and passenger movement, more investments required in rail infrastructure to enable modal shift.
- Technological transitions are heavily dependent on a clean power sector.
- Solutions need to be identified for the aviation and shipping sector in the future as demand for these sectors increases rapidly.
- Transport planning capacity remains limited leading to mobility plans not getting implemented
- Lack of differentiated strategies for cities based on existing mobility patterns

Assessing Alternate Pathways

Based on the present policy environment, two alternate decarbonization scenarios were assessed. The analysis of present policies highlights a clear focus on technological solutions to improve the road sector through fuel efficiency improvements and alternate fuels. Additionally, India's NDC highlights the role of a modal shift towards railways. Thus, the decarbonization pathways considered here focus primarily on the rapid uptake of EVs, alternate fuels, and modal shift for freight. This allows us the assess the potential of present policies while also accounting for the present and future state of technology.

Scenario 1: Electrification of easier-to-transition segments

This scenario looks at a situation where increased focus on EVs and associated infrastructure leads to mass-scale adoption of EVs, but other strategies remain nascent. However, high EV penetration is considered only for easier-to-transition segments. Thus, high penetration of EVs is considered for two-wheeler, three-wheeler, private cars, LCVs, and urban buses. At the same time, the hard-to-abate road segments continue to remain dependent on diesel. The share of rail in freight and passenger movement also remains constant.

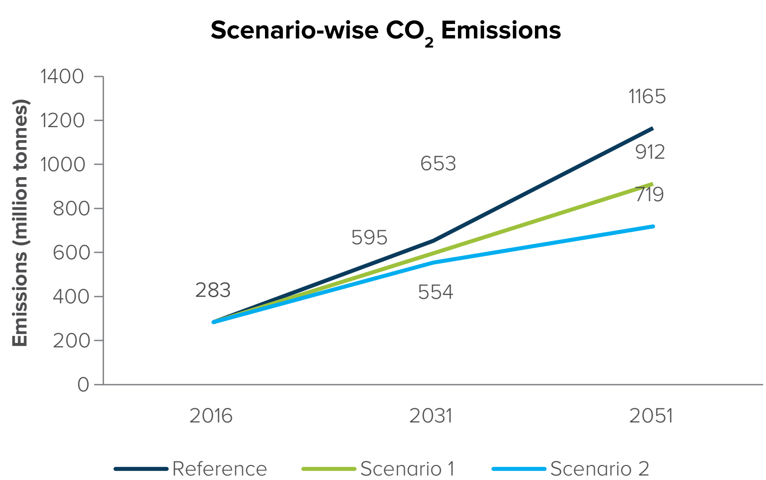
This scenario leads to a 14% and 26% reduction in the total energy requirement in 2030 and 2050, respectively. This leads to a reduction in CO_2 emissions of 9% and 22% in 2030 and 2050, respectively compared to the BAU scenario. The emission intensity of GDP from transport decreases significantly by 30% by 2050 in this scenario. From this, it is clear that even a sole focus on electrification can provide significant benefits from emissions given the present state of technology.

Scenario 2: Electrification combined with solutions for hard-to-abate road segments

The second scenario combined electrification in scenario 1 with solutions for the hard-to-abate road segments, specifically intercity buses and HDVs. Two solutions were combined, considering the limited number of technologies available:

- Faster uptake of EVs, fuel cell vehicles, and LNG for trucks and intercity buses based on the present state of technology and moderate assumptions regarding technology improvements.
- Faster modal shift to rail for freight movement, assuming a 45% share of rail in freight movement by 2040.

This scenario leads to a 17% and 35% reduction in the total energy requirement in 2030 and 2050; respectively. CO_2 emissions are estimated to reduce by 15% and 38%, in 2030 and 2050, respectively compared to the BAU scenario. The emission intensity of GDP from transport decreases significantly by 48% by 2050 in this scenario.



Further Actions for Deep Decarbonization

Many actions in the public and private sectors are already targeted towards decarbonizing transport. The previous analysis shows that the present policy focus has significant potential to reduce carbon emissions, at least at the point of use. However, the overall effectiveness of technology-based changes will depend heavily upon the transition to green sources in the power sector. However, these actions on their own are unlikely to be enough, deep decarbonization will require a mixture of strategies within the avoid, shift and improve framework. The below table lists out the broad strategies which must be further pursued and some of the broad actions for different stakeholders, more detailed analysis is carried out in Chapter 4.

Broaden scope of EV policies

Central and state governments

- Large scale public investment in charging infrastructure
- Promote indigenous manufacturing of batteries by identifying long term sources for raw materials and providing economic incentives

Original equipment manufacturers

- Collaborate with potential buyers to understand issues in existing EV models and improve the performance of future models.
- Identify risk-sharing mechanisms to distribute the risk of financing EVs

Foster innovation in low-carbon technologies for heavy-duty long-distance segments

Central and state governments

- Direct funding and support for research organizations involved in low-carbon technology research
- Institute technology-agnostic economic incentives for low carbon trucks and buses

Original equipment manufacturers

- Increased funding for R&D of low carbon technologies
- Set targets for shifting away from the manufacture of diesel-based trucks and buses

Improve the efficiency of the logistics sector

Central government

- Fuel economy standards and emission standards for trucks should be revised periodically.
- Introduce economic incentives to promote the scrapping of older trucks.

Logistics sector

- Ensure optimal usage of truck capacity
- Periodic upgrade of obsolete vehicles
- Improve placement of warehouses to improve load factors and reduce empty trips

Improve public transport

Central government

- Increase fund allocation for bus procurement under centrally sponsored schemes.
- Encourage the use of PPP models by setting appropriate conditions in central schemes.

State government

- Setup overarching body for administering urban transport which can coordinate actions of the multiple agencies involved at present.
- Improve first and last-mile connectivity through safer streets, cycling infrastructure, and integrated IPT modes.
- Reduce or remove taxes on revenues of financially constrained STUs

State transport undertakings

- Explore non-fare revenue generation.
- Provide training in PPP models to executive staff.
- Implement improvements in bus design for improved passenger comfort and safety
- Tie up with IT companies to provide better IT-enabled services for customers

Civil society

- Create a democratic demand for an efficient and accessible public transport system.

Enable modal shift to railways

Central government

Increase in investment in railways from to 1.2% of GDP by 2030 as per NTDPC committee recommendations

Indian railways

- Expedite delivery times of infrastructure projects, especially the upcoming DFCs.
- Improve operating ratio for passenger services.
- Incentivize premium passenger services, particularly medium distance up to 700 kilometers and overnight travel.
- Adopt a more business-like approach to freight tariff setting.
- Enable decentralized tariff setting
- Create sustainable multi-modal business models for containers and parcel movement

Control growth of motorization rate

Central government

- Ensure implementation of NMT related objectives highlighted in national-level urban policies through economic incentives, competitions, etc.

State governments

- Ensure implementation of NMT related objectives highlighted in national-level urban policies through economic incentives, competitions, etc.
- Establish dedicated cycling lanes after assessing existing and potential utilization.
- Establish pedestrian-only streets in different parts of the city.
- Relocate/remove existing structures that impede pedestrian movement.
- Introduce relevant congesting pricing models in congested stretches in larger cities.

Corporate sector

- Facilitate remote working arrangements.
- Incentive-based schemes to encourage employees to use NMT for their commute.
- Provide subsidized transit passes, subsidized car-pooling services, and tax benefits for using mass transit modes.

STUDY BACKGROUND

The transport sector is a crucial aspect of any economy and is a major catalyst for development. This is even more evident in an increasingly global economy, where economic opportunities are closely linked to the mobility of people and freight. With the global economy growing at an unprecedented pace in the last few decades, the transport sector has also been expanding rapidly. However, this growth has been associated with several negative externalities, especially climate change. The sector is already responsible for emitting around 23% of the energy-related CO_2 that feeds global warming (International Transport Forum 2020). In the future, carbon emissions from the transport sector are estimated to grow faster than any other sector. Decarbonization of the transport sector is now being taken up seriously by policymakers and is an essential step to achieve global climate change mitigation targets.

Presently, the transport sector has been largely dominated by the consumption of conventional carbon-intensive fuels. The sector accounts for 70% and 99% of the total high-speed diesel (HSD) and petrol consumption, respectively (Nielsen 2013). The energy consumption from transport grew at a high compound annual growth rate (CAGR) of 8.3% between 2006 and 2016 (IEA 2019). Emissions from the sector have also seen a rapid increase, with CO2 emissions increasing by 33%, between 2011 and 2014 (MoEFCC 2018). The increase in energy consumption and emissions has been driven by unprecedented growth in the road transport sector. Further, the road sector is characterized by a heavy dependence on energy-intensive personal modes of transport. Recent data shows that around 87% of total registered vehicles in India are two-wheelers and cars. The freight segment has been a significant driver of increasing demand for HSD. Despite having a small share in total registered vehicles, these vehicles account for almost 40% of the diesel consumption within the transport sector (International Transport Forum 2020).

Decarbonization of the transport sector is an essential step towards achieving India's nationally determined contributions (NDCs) and net zero emissions by 2050. The present gasoline-dependent pathway will need a major overhaul to enable the transition. This will require large-scale investment from both public and private sectors in low-carbon mobility. However, there is still uncertainty regarding the feasibility and potential of different approaches to achieve decarbonization. Strategies for decarbonization of the transport can be broadly classified into *Avoid, Shift, and Improve* (A-S-I):

- *Avoid* refers to the need to reduce the requirement for motorized travel and trip lengths. This strategy essentially focuses on reducing the overall demand while not affecting the mobility needs of the population. This requires denser cities, with residential, work, and leisure districts becoming more connected and intermixed through transit-oriented development. Transport demand management is also an important part of this strategy.

- *Shift* seeks to improve the efficiency of individual trips, which requires a modal shift from the most energy-consuming modes (e.g., private cars, diesel trucks, etc.) to more environment-friendly modes (e.g., mass transit systems, railways). This shift is required both for passenger and freight movement. One of the pre-requisites for this strategy is the availability of energy-efficient modes, which can provide the same services as existing modes
- *Improve* focuses on better vehicle and fuel efficiency as well as optimization of the operational efficiency of public transport systems. This strategy also focuses on improving the energy sources powering the transport sector. Within this, approaches such as reducing vehicle weight and shifting to zero-emission vehicles have been considered for vehicles trips that cannot be avoided or shifted to other modes.

The transport sector in India is unique in many ways. Indian cities are naturally dense and well suited for cycling and walking. Trip distances, especially for work trips, are much lower compared to more developed nations. Lower per capita income also leads to the prevalence of a large set of captive users who are forced to avail of the cheapest available options (Roychowdhury and Dubey 2018). Traditionally, Indian cities have been characterized by a high share of non-motorized transport and public transport. With rising incomes, growing automobile industry, and better roads there has been a gradual shift away towards private modes of travel. However, even now a large part of the population continues to use non-motorized modes and public transport for their daily travel needs. Thus, relevant strategies for India could be quite different from other countries, with an increased focus on retaining the share of sustainable modes of travel.

The Government of India has already implemented a plethora of policies towards improving the sector. However, there is a great deal of uncertainty regarding the most effective pathways and ways of implementing different strategies. With new technologies entering the market at a fast pace, policymakers face a difficult task to promote the most optimal strategies and deploy the most effective policy levers.

This study aims to better understand the implications of the most prominent decarbonization strategies. Based on the analysis, we identify further actions that can enable the transition to a decarbonized transport sector in India. The broad objectives of the study are outlined here:

Objective 1: Current trends and policy analysis

- Evaluation of present and future energy consumption and emission trends across the road, rail, and aviation sectors:
  - Review existing trends and policies in the transport sector
  - Forecast future transport demands across road, rail and air till 2050.
  - Create baseline scenario based on the progress of current policies

Objective 2: Mapping and assessment of alternate decarbonization pathways

- Map segment-wise decarbonization options
- Examine potential emission reduction from decarbonization strategies identified based on present policy direction
- Create a policy roadmap identifying further actions needed for decarbonizing the transport sector

Chapter 1:

OVERVIEW OF INDIAN TRANSPORT SECTOR

The transport sector in India has to cater to the diverse mobility needs of more than 1.3 billion people. Driven by increasing economic growth and population expansion, transport activity has grown more than seven-fold since 1992. Even now, the sector is not developed enough to keep pace with the passenger and freight demand and is often seen as a lag on economic activity (World Bank 2011). Given the myriad mobility requirements, the sector has also evolved uniquely.

Modal Split

The transport sector in India is diverse, with both road, rail, and air playing an important role. However, the relative modal share between road and rail has changed significantly since Independence. Both passenger and freight movements were dominated by rail in the decades till the 1980s. Since then, large-scale investment in road infrastructures, such as highways and rural roads, has led to an unprecedented increase in the share of the road sector (Chaudhury 2005) .

Freight movement is primarily dependent on road transport; around 80% of the tonne-kilometers (TKM) in 2016–17 from land transport can be attributed to the road sector. The TKM carried by road transport increased by almost five-fold from 494 million tonnes in 2000–01 to 2260 million tonnes in 2016–17. Freight vehicle sales have also increased at a fast pace. The compound annual growth rate (CAGR) of freight vehicle sales was 9.12% throughout 2007–17, which was an increase of 10% from 1991–2001 level (MoEFCC 2018). In contrast, the share of rail in total land freight movement has declined from 39% in 2000–01 to 33% in 2010–11 and further to 22% in 2016–17 as per estimates from Ministry of Road Transport and Highways and Ministry of Railways.

The present dependence on the road sector is a major reversal of historical trends. Rail was the most dominant mode for moving freight in India till the 1980s. Recently, the share of rail in total land freight movement has declined from 39% in 2000–01 to 33% in 2010–11 and further to 22% in 2016–17 (Figure 1).

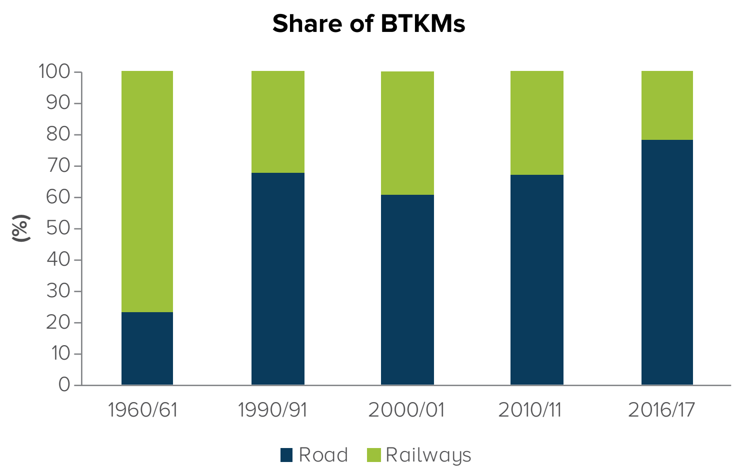


Figure 1: Modal split of freight demand

Source: *MoRTH Yearbook, 2017-18 & Railway Statistical Summary , 2018-19*

The dependence of road transport for passenger movement is even more pronounced, almost 95% of the land-based passenger movement could be attributed to road transport in 2016—17 (Figure 2). This is also a reversal of historical trends; in 1960–61 the share of road transport was only 42%. The growth of road transport has also been characterized by increased use of private modes of travel. New vehicle registrations have been dominated by private modes, with two-wheelers accounting for the highest share (73.86%) followed by the combined share of cars, jeeps, and taxis (13.3%) in 2017. On the other hand, bus sales have grown at a much slower pace, making up less than 1% of the total vehicle registrations in 2017 (Figure 3). In contrast, railways have seen a continuous decline in both sub-urban and non-suburban services. The number of passengers in suburban railway transport declined by 3.7% in 2019–20 as compared to the previous financial year (2018–19). In the non-suburban sector, traffic declined by over 4% during the same period.

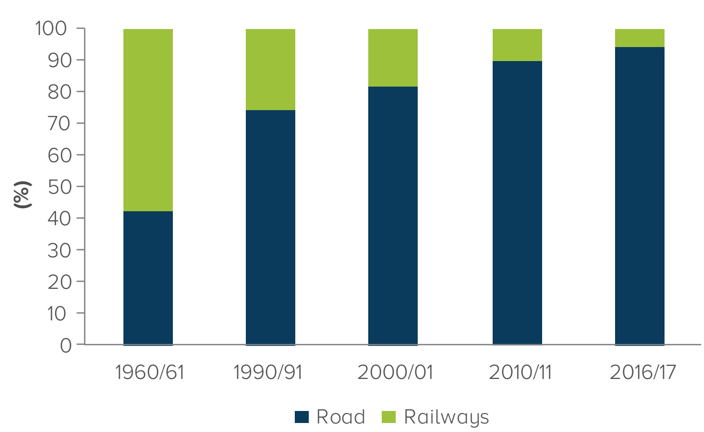


Figure 2: Modal split of passenger demand

Source: *MoRTH Yearbook, 2017-18 & Railway Statistical Summary , 2018-19*

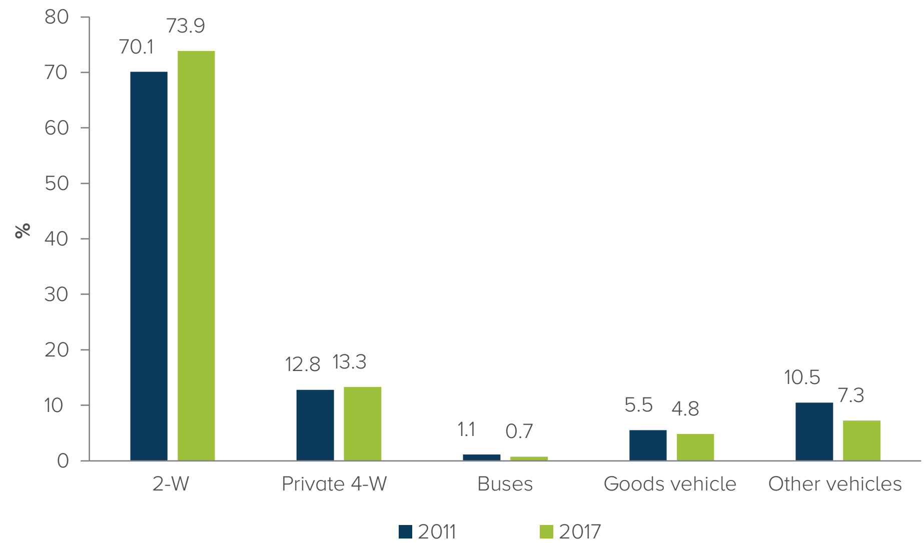


Figure 3: Share of different segments in new vehicle registrations
Source: *MoRTH Yearbook, 2017-18*

The Indian aviation industry has emerged as a fast-growing sector as well. Air movement grew at a CAGR of 7.2% between 2009 and 2019. Air travel has managed to capture a sizeable share of long-distance passenger movement. Domestic passenger traffic registered a CAGR of 13.53% between 2008–09 and 2018–19 while the international passenger traffic grew at 8.24%. In 2016–17, air travel accounted for 3% of the total passenger movement (Figure 4).

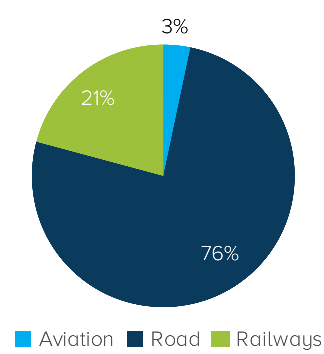


Figure 4: Share of different modes in total passenger demand
Source: *MoRTH Yearbook, 2017–18, Railway Statistical Summary, 2018–19 & DGCA statistics*

Fuel Consumption

The transport sector has been largely dependent on the consumption of carbon-intensive fuels. The sector alone accounts for 70% and 99% of the total high-speed diesel (HSD) and petrol consumption, respectively (Nielsen 2013). This has led to continuously rising import dependence on crude oil, which presently stands at 84%.

The over-reliance on road transport has severe negative consequences for energy and fuel consumption. The usage of HSD in road transport has increased by approximately two-fold from 25.16 million tonnes in 2000–01 to 54.72 million tonnes in 2019–20 (Figure 5). Heavy commercial vehicles (HCV), light commercial vehicles (LCV), and buses account for 40% of the total diesel consumption. The private and commercial four-wheelers account for 13.15% and 8.94% of the diesel usage, respectively. About 99.6% of petrol consumption in India is from road transport, of which two-wheelers account for the highest share (61.42%) followed by four-wheelers (34.33%) and three-wheelers (2.34%) (Nielsen 2013).

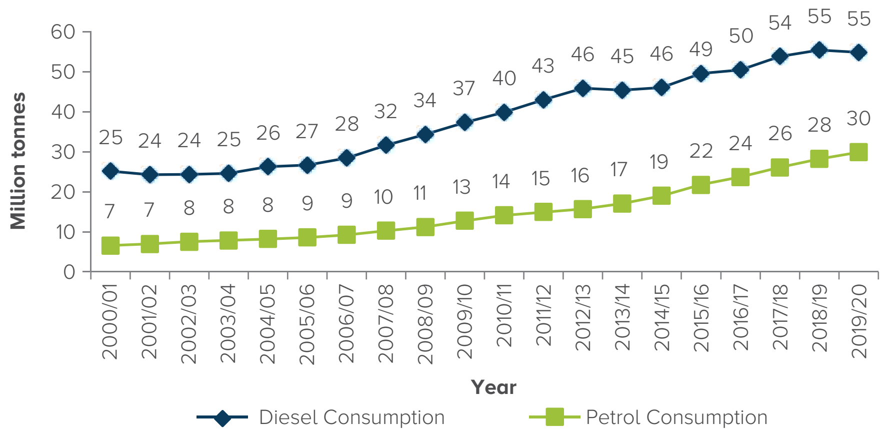


Figure 5: Fuel consumption by road transport

Source: *Nielsen (2013)*

For Indian Railways, the primary energy sources are electricity and diesel. Recently, Railways has seen a significant switch towards electric traction, with large-scale electrification of broad-gauge lines (Figure 6). In 2018–19, 54% and 63% of the total train km related to passenger freight services, respectively, was powered by electric locomotives. This is reflected in the overall fuel consumption trends for railways. Diesel consumption increased by only 9% between 2010–11 and 2018–19, whereas electricity consumption has increased by more than 30% (Figure 7).

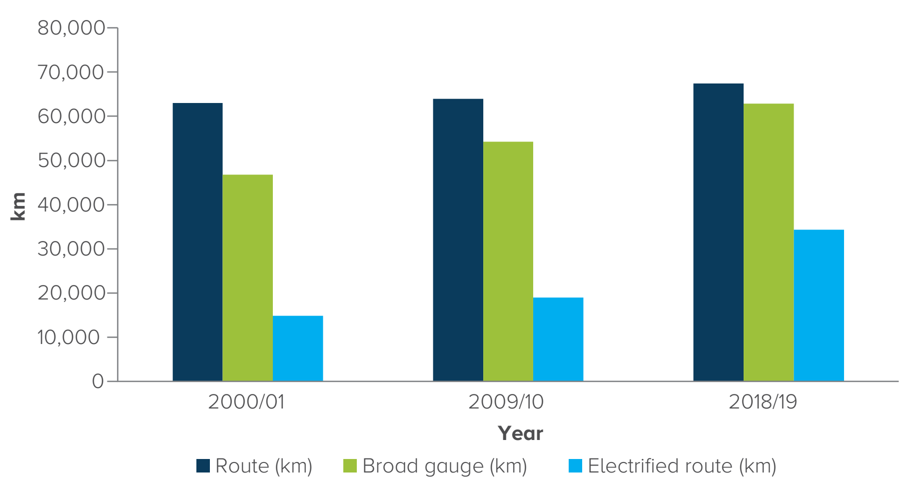


Figure 6: Status of IR's rail network and electrification of route

Source: *Railway Board*

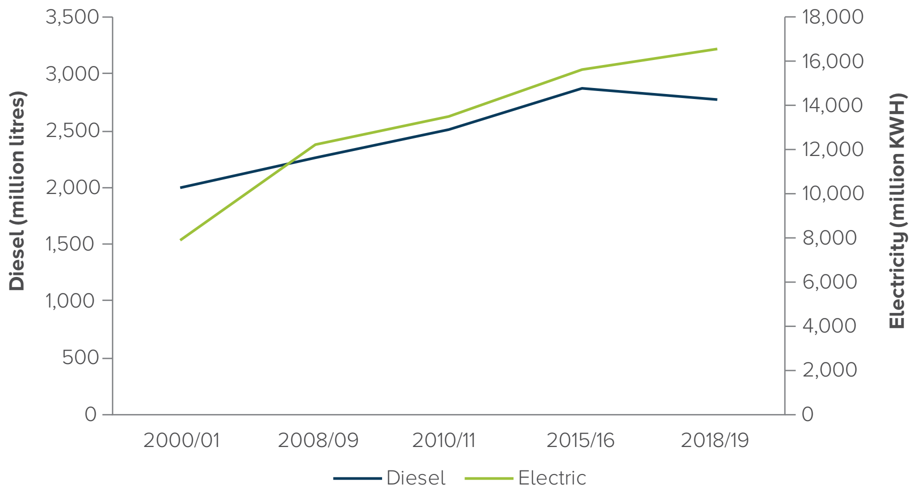


Figure 7: Relative fuel consumption on Indian Railways

Source: *Railways Statistical Summary, 2018–19*

The aviation sector is completely dependent upon kerosene-based aviation turbine fuel (ATF). The ATF usage in India has been rising continuously over the last two decades. In the last five years, the consumption of ATF has grown at a CAGR of almost 8% (Figure 8).

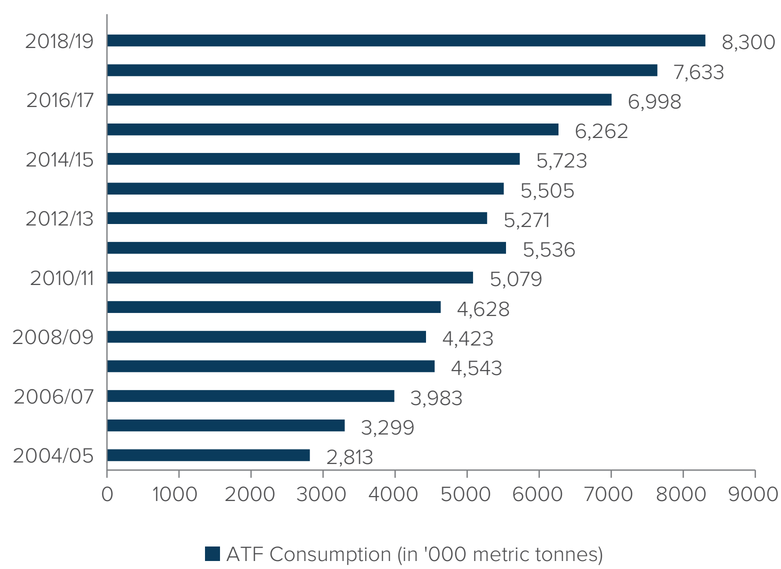


Figure 8: Relative fuel consumption on Indian Railways

Energy and Emissions

The dependence on road transport and gasoline-based fuels has significant implications on energy and emissions. Road movement is undeniably less energy efficient than rail. The National Transport Development Committee (NTDPC) found that rail emits 17-gram CO_2 equivalent per PKM as compared to 84 grams per PKM in the case of road transport. Similarly, rail transport emits 28-gram CO_2 equivalent per NTKM as compared to 64 grams per NTKM in the case of road transport (National Transport Development Policy Committee 2014).

Energy consumption from the transport sector has been growing continuously (Figure 9). Between 2008 and 2018, energy consumption from transport increased by 22%—a very high growth. The highest year-on-year growth was observed in 2014 when energy consumption increased by almost 10% in one year.

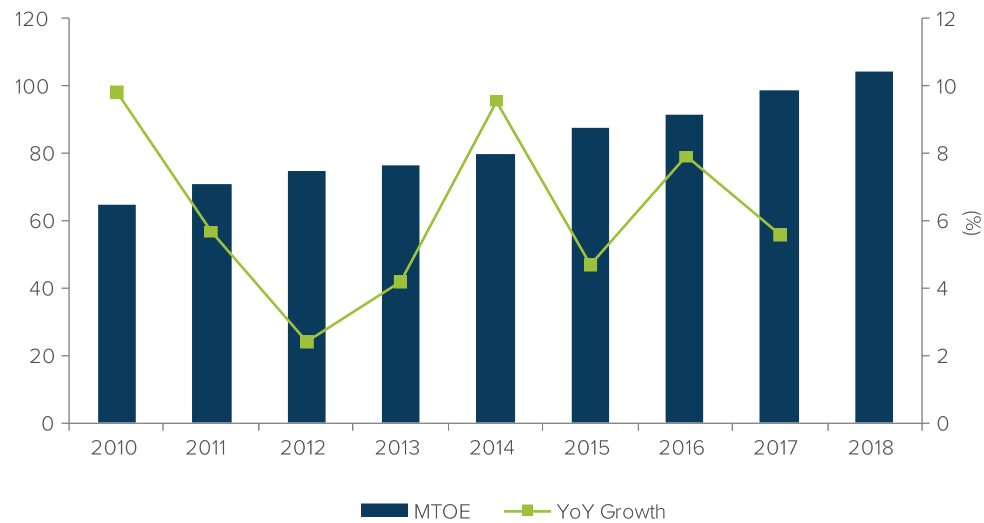


Figure 9: India transport sector energy balance
Source: *TEDDY, 2018–19*

The increase in energy consumption has translated into a significant increase in emissions from the transport sector. India's Third Biennial Report (2021) estimates that 274 million tonnes of CO_2 equivalent emissions could be attributed to the transport sector in 2016 (MoEFCC 2021). This represents about 13% of the net emissions from the whole economy. This is an increase of around 10% from the estimates for 2014 in the Second Biennial Report (2018). A 10% increase in two years signals rapid increase in transport activity and reflects some studies which suggest that the transport sector could see the largest increase in emissions among all sectors (Wang and Mengpin 2019). Unsurprisingly, the road sector was found to be responsible for around 90% of the emissions in 2016 (Figure 10). The aviation sector, despite being responsible for a very low share of demand, still had a higher share than the rail sector, signaling the higher energy efficiency of the sector in India.

Overall, there has been a significant increase in motorization in India. The road sector has grown faster than other sectors and become the main mode for both passenger and freight movement. This has led to an accelerated increase in carbon emissions from the sector in the last two decades.

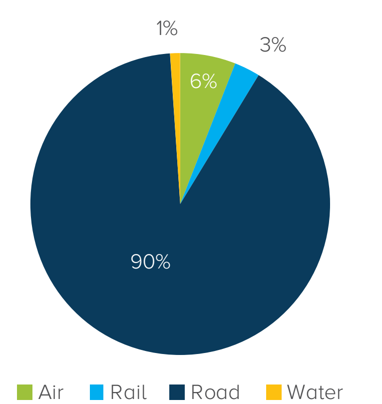


Figure 10: Share of different modes in total transport CO_2 equivalent emissions
Source: *India's Third Annual Biennial Report, 2021*

Chapter 2:

DECARBONIZATION POLICIES IN THE TRANSPORT SECTOR

Key Messages

- Historically high investment in road infrastructure leading to major improvement in road connectivity
- Focus on improved vehicle efficiency through introduction of ambitious fuel efficiency norms
- Strong policies for promoting electric mobility at both Central and State level
- Early recognition of the role of alternate fuels and focus on identifying a clear road map for enabling these fuels
- Rapid advances in expanding metro systems
- Public bus system remains largely underfunded
- Historically low infrastructure investment in railways, some positive developments since 2015
- Largely technology-centric approach, policies which focus on reducing and shifting transport demand have been given less importance.

Historically, policymakers have largely focussed on expanding transport infrastructure to meet increasing demand. The focus has been on augmenting infrastructure for all transport modes. The road sector has seen the largest outlay, leading to massive growth in road connectivity. An estimated 44% of all transport funds are allocated for road construction alone (Sharma and Rajput (2017). As a result, the total road network has grown at a CAGR of 3.9% between 2007 and 2017, leading to a road density of 1.48 km/sqkm, higher than most comparable countries (TIFAC 2016). The Golden Quadrilateral Highway project, Pradhan Mantri Gram Sadak Yojana (PMGSY), and the Bharatmala project are examples of some flagship programme.

The development of urban transport infrastructure has also been a key focus area. The National Urban Transport Policy, JNNURM, Smart City project, and AMRUT are some recent urban policies with a focus on transport. While these policies have overarching goals of promoting holistic and integrated transport, implemented projects have largely focussed on improving road infrastructure. The bulk of expenditure by city governments on transport infrastructure still focuses on building new roads, bridges, and flyovers (Shakti Foundation 2017).

In the past, the transport policies have been driven by the dual goals of economic growth and social development. The multi-fold increase in transport activity has brought environmental issues into consideration. Policies related to decarbonization and pollution reduction have come up in the recent past. This section highlights the most prominent policies and provides a high-level assessment of the areas of focus and the gaps in present policies.

Status of Transport Decarbonization Policies

As part of its Nationally Determined Contributions (NDCs), India has pledged to reduce carbon emission intensity of GDP by 33%–35% of 2005 level by 2030. The specific actions pledged for the transport sector are highlighted in the box below. The NDCs show a clear focus towards shifting away from private/low occupancy modes to mass transit systems, such as buses and metros. It also recognizes the need to shift away from the road sector to more energy-efficient modes, such as rail and water transport. The target of 45% share of rail in land transport is a very strong ambition to this end. Improving the road sector through electric vehicles, fuel efficiency improvements, and biofuel blending is also mentioned. However, specific emissions reduction targets for the transport sector are not provided in the NDCs.

Transport in India's NDC

- Increase share of rail in land transport from 36% to 45%
- Reduce 457 million tonnes of CO_2 emissions through building dedicated rail freight corridors (DFCs)
- Promoting growth of coastal shipping and inland transport
- Focus on 'moving people' rather than 'vehicles' through Mass Rapid Transit Systems and mass urban transport projects
- Develop 140,000 km of Green Highways
- Improve fuel efficiency, promote electric vehicles, and biofuels

Though NDCs provide a good guide, it is necessary to formulate policies that focus on the targeted areas of decarbonization. The following section analyses the performance related to some of the goals.

Fuel efficiency

India has a long history of enforcing emission norms. The first set of norms were introduced for petrol and diesel vehicles in 1991/92. The National Auto Fuel Policy laid down the road map for the introduction of Bharat Stage emission standards. These norms focus specifically on the reduction of air pollutants, which require general improvements in vehicle performance.

Specifically related to fuel efficiency, Corporate Average Fuel Economy (CAFÉ) norms introduced in 2017 have shown good results for passenger cars. Under these norms, the weighted average CO_2 emission from a manufacturer's production line must be less than 130 gm/km till 2022 and below 113 gm/km thereafter. The results have been encouraging so far. Estimates suggest that the fleet average CO_2 emission for FY 2018–19 was 121.9 g/km (International Council on Clean Transportation 2020). However, the present norms are still above the average limits in Europe and the next stage should focus on stricter norms. The COVID-19 crisis might have provided a setback to this momentum with auto manufacturers facing problems due to reduced revenues.

For commercial vehicles, the progress has been less encouraging. The Bureau of Energy Efficiency notified fuel efficiency standards for commercial vehicles above 12 tonnes in 2017. Standards for vehicles between 3.5 to 12 tonnes were notified in 2019. However, compliance has not been very encouraging. Manufacturers had objections related to standards being imposed on individual vehicles and not the whole fleet. There was also a major issue with the testing system, related to using lab-based tests compared to simulations. This has led to some bottlenecks in the implementation of these standards so far.

Electric mobility

Electric mobility has been promoted in a big way. Both Central and State governments have notified EV policies, providing purchase and manufacturing incentives. The National Electric Mobility Mission Plan (NEMMP) by the Department of Heavy Industries (DHI) has set the stage at the national level. This has been followed by around 21 states with notified or draft EV policies. Other relevant departments, such as the Ministry of Power and the Ministry of Housing and Urban Affairs (MoHUA), have also been involved in developing charging infrastructure. There has been significant support from the automobile industry as well, with both legacy OEMs and new start-ups getting involved in EV manufacturing.

Despite the policy push, actual EV sales have remained below the ambitious targets. Only around half a million EVs have been sold so far, compared to the NEMMP target of 6-7 million EV sales by 2020. Around 95% of the EV sales have been in the two-wheeler and three-wheeler categories. So far, the policies have focussed on certain intra-urban segments, given the availability of e-vehicles. Two-wheelers and three-wheelers have always been at the forefront. Recently, urban logistics vehicles have also been pushed in a big way. City buses are already covered under the FAME-II incentive scheme, with 5595 e-buses approved for procurement. However, for larger trucks and intercity bus operations there remains some uncertainty regarding appropriate policy interventions.

Mass transit systems

India has made great progress in expanding its urban metro systems. As of 2021, 389 km of the metro network has been constructed in India covering 15 cities. Metros have caught the attention of policy makers in a big way and innovative financing mechanisms have been deployed. As an example, nearly three-quarter of Delhi's transport budget is on metro expenditure (Sahai and Bishop 2010). However, the ridership on almost all metros has been well below projected levels. In Bangalore, daily ridership has been less than half of the projected levels.

In contrast, inadequate investment in the public bus system has resulted in a supply gap and a lack of modernized services. India only has around 1.2 buses per 1000 people, much lower than similar countries (NITI Aayog & The Boston Consulting Group 2018). A 2016 study found that Indian cities would require investment to the tune of $15.4 billion to procure new buses to meet expected demand (Janaagraha Centre for Citizenship and Democracy 2020). It has also led to over-aged vehicles accounting for 27% of the total fleet size of State Transport Undertakings (STUs), leading to poor fuel efficiency and reduced passenger comfort (Ministry of Road Transport & Highways 2020). Recently, efforts have been made to aid bus procurement through central policies such as JNNURM, Smart Cities, and AMRUT. The 2021–22 Budget also included a high investment of Rs 18,000 crore for bus procurement. However, STUs continue to incur significant operating losses of around Rs 14,000 crores annually. Improving their financial positions will be a key step towards improving bus procurement and improving services.

Modal share of railways

Since the 1960s, freight and passenger loading by railways has increased by 1344% and 1642%, respectively. However, route kilometers have only grown by 23% and track doubling has increased only 289%. The present infrastructure has been unable to deal with the growing demand, leading to significant operational constraints. As a result, the productivity of rail freight and passenger services in India is much lower than in other developed economies. The underlying reason has been historical underinvestment in rail in favour of expanding road infrastructure. Since the 2000s, annual public infrastructure expenditure on roads and bridges alone has been around 1–1.2% of GDP, whereas for railways it has been around 0.4–0.8% of GDP.

In contrast to the NDC goals, the share of rail has been continuously declining. Present estimates suggest that the share of rail in freight movement is around 25%–27% (International Council on Clean Transportation 2020), much lower than the 36% share identified in 2005 (Planning Commission 2013). Infrastructure bottlenecks and lack of competitiveness with road have been the major reason for the decline in the modal share of rail.

Recently, there have been some positive developments in terms of infrastructure augmentation. Since 2015, investments have been stepped up after the government announcement of a $137 billion-dollar five-year investment plan. Since then, the running track has increased by around 10,000 km. Additionally, around 6000 coaches and 40,000 wagons have been added to the rolling stock, a major increase. Electrification efforts have also received a significant boost, more than 25,000 km of running track have been electrified since 2015. Significantly, two dedicated freight corridors (DFCs) are likely to be fully commissioned by 2023. This is after multiple delays stretching over 10 years, mostly related to land acquisition. Another four DFCs are planned by 2030. Thus, Railways have become proactive in infrastructure augmentation. Going forward, this will have to be supplemented by better marketing policies and more competitive pricing policies.

Promotion of alternate fuels

The government has taken steps to encourage the use of natural gas in transport. Compressed natural gas (CNG) has been a long-term area of focus, prompted by the Supreme Court mandating the use of CNG for commercial vehicles in Delhi. Presently, CNG has spread to some urban centres, with Gujarat and Maharashtra having the highest CNG usage. Commercial segments such as taxis and autos have seen the highest adoption of CNG. Recently, the Ministry of Petroleum and Natural Gas (MoPNG) unveiled a Natural Gas Infrastructure Development Plan to set up 10,000 CNG stations over the next 10 years.

The Amendment to the Central Motor Vehicles Rules in 2017 to include liquefied natural gas (LNG) as an automobile fuel was an important first step for the introduction of LNG vehicles. Additionally, India is set to see investments to the tune of around Rs. 10,000 crores in three years to create infrastructure for using LNG as a fuel for long-haul transportation. This will include the setting up of 1000 LNG stations. It is expected LNG would be most relevant for heavy-duty trucks and buses.

The proposed amendment to the Central Motor Vehicles Rules, 1989 to include safety standards for fuel cell vehicles suggests acceptance of hydrogen as a future alternate fuel. NITI Aayog has also recommended the use of H-CNG by utilization of the existing piped-gas infrastructure in Delhi. It has further recommended that H-CNG be notified as an automotive fuel. The use of H-CNG has already been tested as part of a trial run in buses in Delhi. The common consensus seems to be that fuel cell vehicles could be a long-term solution for heavy-duty vehicles where the battery requirements for EVs may be counterproductive.

Non-motorized transport

The share of non-motorized transport (NMT) in India has been traditionally high, nearly 30% in the TIER-1 cities and 60% in the smaller cities. The average trip length of NMT is around 10 km for mega cities and 4 to 6 km for medium-sized cities (Ministry of Urban Development 2008). Walking and bicycle are the most preferred modes for work trips (TERI 2018). Despite the importance of these modes, dedicated investment in NMT infrastructure has been scarce. This has led to serious safety concerns and a steady decline in NMT usage. In 2017–18, 22% of all fatalities from road accidents were NMT users.

Several urban policies refer to NMT in their overarching objectives. Examples of NMT investment include JNNURM, Urban Transport Policy, 12th five-year plan. The focus has been on enabling NMT to provide effective first-and last-mile connectivity options for public transport. However, actual investment has been minimal. A recent study found that only 2% of the transport budget in five major cities was devoted to NMT infrastructure (Shakti Foundation 2017). There is a lack of dedicated city agencies with the financial capability and expertise for planning pedestrian and cycling infrastructure. Recently, the Chennai Non-motorised Transport Policy mandated that 60% of corporations' transport budget be spent on NMT. More states will need to take up this cause through similar policies to provide safe access to NMT.

Inland water transport

Despite having an extensive river network, the modal share of inland waterways (IWTs) has been traditionally low, that is below 1%. The National Waterways Act, 2016 was a clear indication that the government was seriously taking up the development of inland waterways. The policy had initially identified 111 national waterways for development. The push by the government was backed by the World Bank announcing large-scale loans for developing waterways starting with a $105 million loan to develop National Waterway-1. This has led to a steady increase in actual goods transported on the waterways, increasing from 55.47 million tonnes in 2016–17 to 73.64 million tonnes in 2019–20 (Inland Waterways Authority of India n.d.).

However, there have been some issues while developing waterways. From the 37 waterways that were to be developed by 2019, work has only begun on 16 of them, most still at initial stages (Dharmadhikary and Verma 2021). The budget allocations have also been lower than the Rs 2000 crore year investment announced initially; Budget 2020–21 allocated only Rs 623 crores to IWTs. Initial expectations regarding the suitability of different waterways had to be revised since 63 of them were found to be inviolable. The issue has been the amount of dredging required to make these feasible, leading to untenable costs and ecological concerns.

Classification of Decarbonization Policies

The present policies were classified according to the approach and type of instrument used (Table 1) (Holden and Linnerud 2011). It is clear that decarbonization has already received significant attention from policy makers.

The earliest policies have focussed on improvements in fuel efficiency through enforcement of segment-wise standards, which have been implemented to different degrees. All the recent focus has been on enabling low-carbon technologies in the road sector. The push for EVs through incentives on purchase, manufacturing, and charging infrastructure has been the most prominent strategy. Aside from EVs, there has also been a push for natural gas (CNG, LNG) and hydrogen as transport fuels. Plans and targets have been announced for scaling up enabling infrastructure for these fuels (see annexure).

Overall, there is a clear tendency to promote technological solutions to enable the low-carbon transition. It is also pertinent to mention that air and shipping still have limited decarbonization solutions; the major reason for this is the small share of these modes in the total transport demand. Strategies that focus on reducing and shifting transport demand have been given less importance. The role of modal shift to public transport and rail has been highlighted in India's NDCs, but actual policy action has been minimal. Strategies to reduce travel demand through better city planning, promoting non-motorized travel, and demand management have received some attention in overarching policy documents, but on-ground implementation has been very limited. Specific details about the policies highlighted in Table 1 have been provided in the annexures.

Table 1: High-level assessment of present transport decarbonization policies

<table>
<tr><th colspan="2" rowspan="2">Market-based</th><th colspan="3">Policy Instruments</th></tr>
<tr><th>Regulations</th><th>Infrastructure based</th><th></th></tr>
<tr><td rowspan="3">Policy Approach</td><td>Improve</td><td>➢ Faster Adoption and Manufacturing of Electric Vehicles (FAME) Scheme
➢ State-level EV policies
➢ Scrappage policy
➢ Green tax</td><td>➢ Auto-fuel policy, 2015
➢ National Policy on Biofuels, 2018
➢ CAFÉ-1
➢ CAFÉ-2 (upcoming)
➢ Fuel efficiency standards for M/HDVs
➢ Acceptance of hydrogen and LNG as automotive fuel</td><td>➢ National Electric Mobility Mission Plan
➢ National Hydrogen Mission
➢ Electrification of railway operations
➢ CNG program</td></tr>
<tr><td>Shift</td><td></td><td></td><td>➢ National Rail Plan, 2020
➢ Waterways Act, 2016
➢ Higher budget allocation for buses and metros
➢ JNNURM scheme</td></tr>
<tr><td>Avoid/ Reduce</td><td></td><td></td><td>➢ National Transit Oriented Development (TOD) Policy
➢ Urban Transport Policy
➢ Urban Green Mobility Fund
➢ Smart Cities Mission</td></tr>
</table>

Chapter 3:

MAPPING AND ASSESSMENT OF ALTERNATE DECARBON-IZATION PATHWAYS

Approach and Methodology

To assess different decarbonization pathways, an emissions modelling exercise was undertaken. The broad steps undertaken as part of the exercise are detailed here:

- *Modelling business-as-usual scenario:* A baseline scenario was created by mapping the existing mobility trends and extrapolating them forward up till 2050.
- *Modelling alternate decarbonization pathways:* Two alternate policy scenarios were assessed; these represent a future where certain decarbonization strategies receive major push while others remain nascent.
- *Comparative analysis:* The baseline scenario was compared to the decarbonization scenarios to assess the potential of identified strategies. This comparative analysis was undertaken to assess the impact on energy consumption, emission reduction, and costs at different time point up to 2050.

To model transport sector emissions, the study relied on the TERI Transport Model (TERI TPTM) and TERI's MARKAL (MARKet Allocation) Model. The service demands were estimated using the TERI-TPTM model and fed into the MARKAL model for estimating emissions. The MARKAL models emissions for the whole energy system; the transport sector was specifically used for this study. The details of the modelling approach are provided in the annexures.

This study builds on previous exercises to develop more up-to-date estimates from the transport sector (CSTEP, CEEW, IRADe, PNNL, and TERI 2019 and Paladugula, Kholod, Chaturvedi, et al. 2018). GDP and population estimates have been updated based on the latest data. The data for vehicle stocks has been updated based on the most recent available data from MoRTH, Railways, and DGCA. Inputs related to vehicle utilization, fuel usage, and emission factors have been updated based on an updated literature review. Market shares for different vehicle segments have also been updated up to 2019–20 based on the latest available data from the Society of Indian Automobile Manufacturers (SIAM). Thus, present and future projections also reflect the latest trends that may not have been captured in previous studies. Further, the model has been expanded to incorporate the aviation sector and newer technologies in road transport, such as fuel cell vehicles (FCVs) and LNG.

Scenario Design

Previous studies have already assessed the impact of different decarbonization strategies (Table 2). The base case (business-as-usual) scenarios from these studies suggest that annual CO_2 emissions from the transport sector in 2050 could range from 692 million tonnes to 1446 million tonnes. The wide range is due to the variation in extrapolation methods, utilization inputs, and market shares—this makes it difficult to directly compare the results from different studies. Most studies assess the emission reduction potential of different strategies in isolation. The assessed strategies include electrification, fuel-efficiency improvements, modal shift to rail, demand reduction, biofuels, and promotion of mass transit. The framing of the scenarios is based on normative judgments, such as achieving certain government/global targets or on assumptions derived from present trends.

The conclusions regarding different strategies are diverse. Electrification is assessed in all studies; however, the treatment differs significantly. The ICCT scenario looked at an ideal situation where 95% of all vehicles, including heavy-duty trucks, become electric by 2050. As expected, this provided major benefits with emissions decreasing by an estimated 50% by 2040. In other studies, uptake of EVs was significant for two-wheelers, three-wheelers, and cars. These scenarios suggest that CO_2 emissions could be reduced by 10% to 30% in 2050 from electrification alone.

Fuel efficiency was another strategy found to have significant potential for emission reduction. However, some issues such as increased utilization with fuel efficiency improvements and limits to weight reduction have been highlighted. The benefit of non-technological solutions such as demand reduction and switch to mass transit have been highlighted in the UNEP-DTU study and the multi-model study.

Table 2: Overview of previous studies assessing decarbonization of transport in India

Study ID	Sectors Assessed	Time Horizon	BAU Emissions ($MtCO_2$)	Scenarios Assessed	Emission Reduction Potential
The multi-model study, 2019 (Janaagraha Centre for Citizenship and Democracy (2020)	Road and rail	2050	2030 TERI: 615 PNNL: 376 CEEW: 378 CSTEP:630 2050 TERI: 1,446 PNNL: 692 CEEW: 791 CSTEP:991	**New policy:** government targets are met **High Ambitions:** Government targets are exceeded Within each scenario, the following strategies are assessed: Electrification, increased efficiency, modal shift, demand moderation, and biofuels	Emissions reduction in 2050: New policy Electrification: 6.2%–28% Increased efficiency: 3%–66% Modal Shift: 2%–15% Moderating demand: 7%–15% Biofuels: 3.5%–13% High Ambition Electrification: 7%–24.7% Increased efficiency: 9%–72% Modal Shift: 3.5%–21% Moderating demand: 10%–19% Biofuels: 6%–13.2%
ICCT, 2021 (International Council on Clean Transportation 2021)	Only road transport	2040	2040: 805	**Ambitious electrification scenario:** Around 95% of all vehicle sales to be electric by 2040, including around 95% electrification in heavy-duty segments	50% reduction in CO_2 emissions by 2040
IEA-ETP, 2017	Road, rail, air, and water	2060	2030: 898 2050:1,855	- 2°C Scenario Beyond - 2°C Scenario	61% reduction in CO_2 emissions by 2030 79% reduction in CO_2 emissions by 2050
CEEW, 2020 (Soman, Kaur, Jain, et al. 2020)	Only road transport	2030	2030: 635	**EV30:** 30% EV sales by 2030 **High public transport (PT):** Increased shift to public transport **High shared mobility:** Increased shared mobility	Reductions in CO_2 emissions by 2030: EV30: 6% High PT: 12% Shared mobility: 10%

Study ID	Sectors Assessed	Time Horizon	BAU Emissions ($MtCO_2$)	Scenarios Assessed	Emission Reduction Potential
UNEP-DTU, 2015 (Dhar, Pathak, and Shukla 2015)	Road, rail, air	2050	2050: 1,165	**Sustainable mobility scenario:** Demand reduction, shift to public transport, shift to non-motorized transport **Sustainable logistics:** 48% share of railways in freight movement by 2050 **Fuel economy scenario:** achievement of targets proposed by the Global Fuel Economy Initiative (GFEI) **Electric mobility scenario:** high penetration in 2-Ws and cars	Reductions in CO_2 emissions by 2050: Sustainable mobility: 17.5% Sustainable logistics: 3% Fuel economy: 11.8% Electric mobility: 11%

The scenarios in this study are based on a slightly different approach. We do not look at normative or high ambition scenarios. Instead, the scenarios are designed keeping in mind the present policy and industry focus. Based on the assessment of the transportation sector done in Chapter 2, some major policy trends were identified. The first was a clear focus on technological solutions to decarbonize road transport, involving a switch to cleaner fuels. The most prominent example of this is the increased push for EVs through national- and state-level schemes. This is also accompanied by the promotion of other fuels, such as compressed natural gas (CNG), liquefied natural gas (LNG), and hydrogen. Aside from new technologies, improvements to fuel efficiency and biofuels have also found prominence. The second trend is a focus on shifting freight movement towards rail—this is also embodied in the National Rail Plan, 2020 that aims to achieve a 45% share of railways in freight through infrastructure improvements, as well as India's NDC.

The available technological solutions differ significantly by vehicle segment. For newer technologies, rapid advances can be expected, leading to significant technical and economic changes. Table 3 provides a non-exhaustive assessment of the segment-wise potential of different technologies for the road transport sector. This is based on consideration of multiple criteria, such as total cost of ownership, reliability, technical compatibility, refueling infrastructure.

At present, EVs are the most prominent alternate zero-emission technology. EVs have already seen adoption in certain segments, such as three-wheeler autorickshaws and two-wheelers. To a lesser degree, adoption has also been seen in passenger cars, taxis, and urban logistics (Centre for Energy Finance n.d.). These segments mostly operate in urban settings and have lower daily utilization and are lightweight. This favours EVs since it reduces the required battery size, reducing cost, and overall weight. These segments can be seen as easier to penetrate for EVs. City buses would also be included in this category as they travel short distances on fixed routes and charging infrastructure can be planned for this.

Segments where heavier loads and longer distances are involved still lack zero/low-emission options. The potential for electrification remains low in these segments owing to battery weight penalties, the need for a high-capacity charging network, long charging times, and forced changes in operational patterns. When moving people or goods over long distances, the energy density of the fuel assumes great importance. The energy density of batteries is many orders of magnitude lower than petroleum fuels, making heavy transport more difficult to electrify. Segments with these characteristics would require low-carbon fuel options that mimic the characteristics of petroleum fuels; LNG, hydrogen, and other synthetic fuels could provide the appropriate decarbonization options for these segments. However, presently these technologies remain nascent due to high costs or lack of enabling infrastructure. In our analysis, two road segments with these characteristics are the inter-city buses and medium and heavy commercial vehicles (M/HCVs).

Thus, from the perspective of technological solutions, the road sector can be separated into easier-to-transition segments and hard-to-abate segments. The easier-to-transition segments already have alternate fuel options (specifically EVs), which can be expected to take up significant market shares in the future. The hard-to-abate segments include heavy long-distance transport, specifically intercity buses and trucks.

The aviation sector is another hard-to-abate segment; this sector presently contributes only a small share of total energy consumption and has not received much attention. Very little data is available regarding the costs and reliability of alternate fuel options for aviation. As demand for aviation grows, increased investment in decarbonization solutions will eventually provide a clearer pathway for this sector.

Table 3: Current scenario: non-exhaustive list of alternate low-carbon solutions for the road transportation sector

Vehicle segment	Passenger						Freight			
Fuel	**2W**	**3W**	**4W**	**4W- Taxi**	**Urban Buses**	**Intercity Bus**	**3W**	**LCV**	**MDV**	**HDV**
Petrol	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Relevant with major technology advances	Relevant with major technology advances	Relevant with major technology advances	Technology already exists	Relevant with major technology advances	Relevant with major technology advances
Diesel	Relevant with major technology advances	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists
CNG	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Relevant with major technology advances	Technology already exists	Technology already exists	Technology already exists	Relevant with major technology advances
LNG	Relevant with major technology advances	Relevant with major technology advances	Relevant with major technology advances	Relevant with major technology advances	Unlikely to be a relevant technology	Relevant with major technology advances	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology
Battery Electric	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Relevant with major technology advances	Technology already exists	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Relevant with major technology advances
Fuel Cell	Relevant with major technology advances	Relevant with major technology advances	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Relevant with major technology advances	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology

Technology already exists   Relevant with major technology advances   Unlikely to be a relevant technology

Are present policies enough to enable deep decarbonization of the transport sector? The two alternate decarbonization scenarios were designed to assess this question.

The first scenario looks at the decarbonization of easier-to-transition segments alone. This scenario assumes a rapid uptake of electric and CNG vehicles in these segments while maintaining conservative assumptions for other transport segments.

The second scenario combines electrification with decarbonization solutions for the heavy long-distance road segments. Accelerated penetration of alternate fuels [fuel cell vehicles (FCVs) and LNG] is assumed in this scenario. However, since these technologies are not yet market-ready, large-scale uptake will be difficult, so modal shift could also provide major benefits. Thus, this scenario also assumes that there is a significant shift from road to rail. The share of rail in overall freight demand is assumed to increase rapidly, while rail share in passenger demand grows at a relatively slower pace.

For both these scenarios, future market shares have been calibrated keeping in mind technological advances as well as constraints such as production capabilities, raw material availability, charging infrastructure, and consumer acceptance. The three scenarios have been described below.

Business-as-Usual (BAU) scenario

This scenario is based on projecting forward current market trends in each segment without accounting for any major disruptions. Future uptake of EVs has been kept conservative and is limited to easier-to-transition segments, with very minimal penetration in hard-to-abate segments.

Electrification of railways is also assumed to occur at a slower pace with 100% electrification of track kilometers being achieved only around 2035. Rail share in freight and passenger-km has been assumed to slightly decline in this scenario, in line with present trends. The share of rail in TKMs declines from 26% to 20% between 2015 and 2050, while the share in PKMs declines to 10% from 14% in the same period.

Decarbonization Scenario 1: Electrification for easier-to-transition segments

This scenario looks at a situation where increased focus on EVs and associated infrastructure leads to mass-scale adoption of EVs, but other strategies remain nascent. However, high EV uptake is considered only for easier-to-transition segments. The share of EVs in two-wheelers and three-wheelers are assumed to be high, with around 70% of on-road vehicles in these segments becoming electric by 2050. Personal cars and taxis also see a high level of EV penetration, especially beyond 2030, as battery technology improves and more varieties of vehicles are available at a lower cost. For LCVs, a high level of electrification is assumed with 60% of all on-road vehicles becoming electric by 2050. However, low levels of electrification are assumed for intercity buses and M/HCVs based on the belief that electrification is unlikely to be a long-term solution for these segments.

Overall, the penetration of EVs is assumed to accelerate faster post-2030, given the expected improvement in battery technology and user acceptance. However, the penetration of EVs and CNG in rural areas is assumed to be low till 2040 and accelerates after that. As a result, even in 2050, some on-road vehicles in these segments continue to run on gasoline-based fuels.

Decarbonization Scenario 2: Electrification combined with solutions for hard-to-abate segments

This scenario looks at decarbonization solutions for the hard-to-abate road segments based on present trends. Technological solutions for this segment remain limited and this scenario assumes a combination of different solutions:

– Faster uptake fuel cell vehicles and LNG for M/HDVs and intercity buses, electrification is also considered for certain MDV segments. Buses, EVs, fuel cells, and LNG vehicles are assumed to take up sizeable market shares in this post-2030. Almost 40% of intercity buses are assumed to run on either hydrogen or LNG by 2050. Similarly, for M/HCVs, LNG and hydrogen trucks makeup 40% of all trucks with a gross vehicle weight (GVW) above 12.5 tonnes in 2050.

– A faster modal shift to rail for freight movement is considered. This leads to a 45% share of rail in freight movement by 2040 and 50% by 2050.

Table 4 provides an overview of the modelled scenarios. The specific market shares for the different scenarios are provided in the annexure.

Table 4: Overview of modelled scenarios

Scenario	EV Penetration	Share of Railways		Efficiency Improvement	Uptake of Low Carbon Fuels in Hard-to-abate Segments
		Freight	Passenger		
BAU	Conservative	Decline	Decline	Moderate	Very low
Scenario 1: Electrification for easier-to-transition segments	High in easier-to-transition segments	Reversal of decline, a moderate increase	Reversal of decline, share maintained	Moderate	Very low
Scenario 2: Solutions for hard-to-abate segments	High in easier-to-transition segments	Much higher increase, up to 45% by 2045	Moderately higher increase, up to 23% by 2050	Moderate	High*

*High but based on the present state of technologies and considering significant technological development

Thus, this exercise focuses on a minimal number of strategies that are already prominent. Significantly, fuel efficiency improvements have been kept constant in all three scenarios. However, other studies have previously highlighted the importance of this strategy. The aim is not to undermine the importance of alternate strategies but to assess the relative potential of certain specific strategies to understand to what extent they can lead to the decarbonization of the sector in 2030 and 2050.

Limitations and Assumptions

The modelling exercise aims to assess the potential of certain identified strategies based on an abstraction of the transportation sector in India. The scenarios assessed are not necessarily an accurate depiction of the future, since a limited number of factors and strategies are incorporated in each scenario.

The future market shares in each scenario are based on assumptions identified through a review of the state of technology, technological and economic hurdles, expected future progress, and expert consultations. The market shares for decarbonization scenarios have been kept conservative compared to other studies modelling high ambition scenarios. This is to better understand the realities of the transportation sector under realistic assumptions keeping in mind resource constraints in scaling up enabling infrastructure.

Water transport has not been considered in this analysis.

Results and Discussion

In the BAU scenario, the model predicts that passenger activity will increase three-fold between 2016 and 2050. (Figure 11). This reflects a CAGR of 3.73% till 2030 and a slightly lower rate of 2.09% between 2030 and 2050. Freight activity is estimated to increase even faster, around seven-fold in the same period (Figure 12). This reflects a CAGR of 6.37% till 2030 and a slightly lower rate of 4.99% between 2030 and 2050.

The increase in transport activity is driven by the expected growth in the GDP per capita and the population in this period. It also reflects a low base for transport demand in India. Present vehicle ownership levels in India are well below other similar economies. The predicted vehicle ownership in 2016 from the model was 85 vehicles per thousand population, whereas the ownership in Brazil and South Korea stood at 330 per thousand and 424 per thousand, respectively in 2016 (Ministry of Road Transport and Highways 2018).

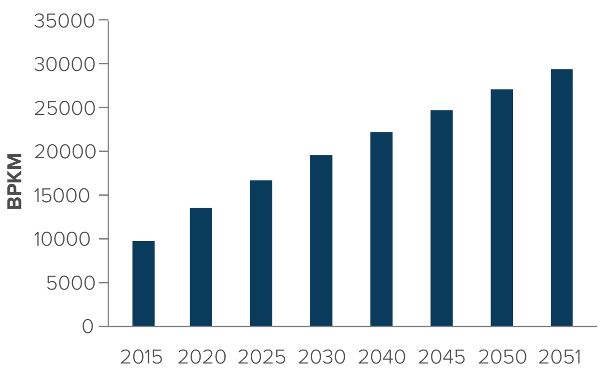


Figure 11: Projected annual passenger transport demand

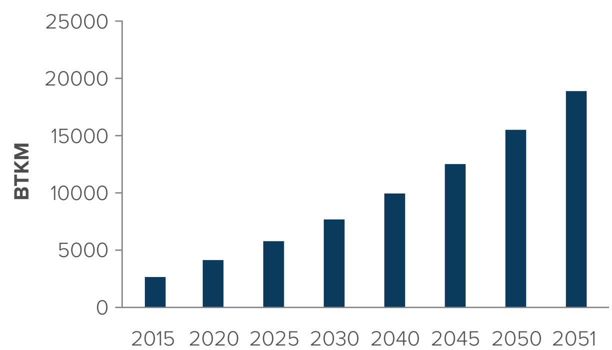


Figure 12: Projected annual freight transport demand

Table 5 shows the share of transport demand met by different segments till 2050. The estimates highlight the over-reliance on the road transport sector, and specifically the role of heavy-duty segments. In the passenger segments, buses account for 64% of the total passenger activity in 2016, followed by two-wheelers (13%), rail (10%), and private cars (5%). Around 80% of the activity from buses comes from intercity and rural buses.

M/HCVs dominate the freight segment, accounting for 58% of freight activity, followed by rail (26%) and LCVs (16%) in 2016. The heavy-duty long-distance segments are the hard-to-abate segments, and presently these segments account for the largest share of transport demand.

In the future, the model predicts the share of rail to keep declining till 2050 for both freight and passenger segment. Share of the road sector in passenger activity is maintained at around 87% even in 2050. Passenger demand from buses declines, taken over by private modes, such as cars and two-wheelers. Specifically, the share of private cars increases from 5% to 15% in 2050. In the freight segment, the decline in rail share is taken over largely by HCVs. The share of HCVs in freight activity increases from 58% to 66% in 2050. The share of air in passenger movements increases constantly to 5% in 2050.

Table 5: Share of different modes in total transport activity for BAU scenario

Segment	2016	2031	2041	2051
BPKMs				
Car	5%	10%	12%	15%
2-W	13%	15%	14%	12%
3-W	4%	8%	9%	11%
Taxi	2%	4%	4%	4%
Bus	64%	58%	52%	48%
Rail	10%	8%	8%	7%
Air	2%	3%	4%	5%
BTKMs				
LCV	16%	15%	14%	13%
M/HCV	58%	60%	63%	66%
Rail	26%	24%	22%	20%
Air	0.09%	0.5%	1%	1.2%

The overall energy demand from transport increases more than four-fold between 2016 and 2050 (Figure 13). The major share of energy consumption comes from HCVs and buses at all time points, both depend heavily on diesel. As a result, the share of diesel and petrol in the BAU scenario remains as high as 82% even in 2050—decreasing only slightly from 90% in 2016.

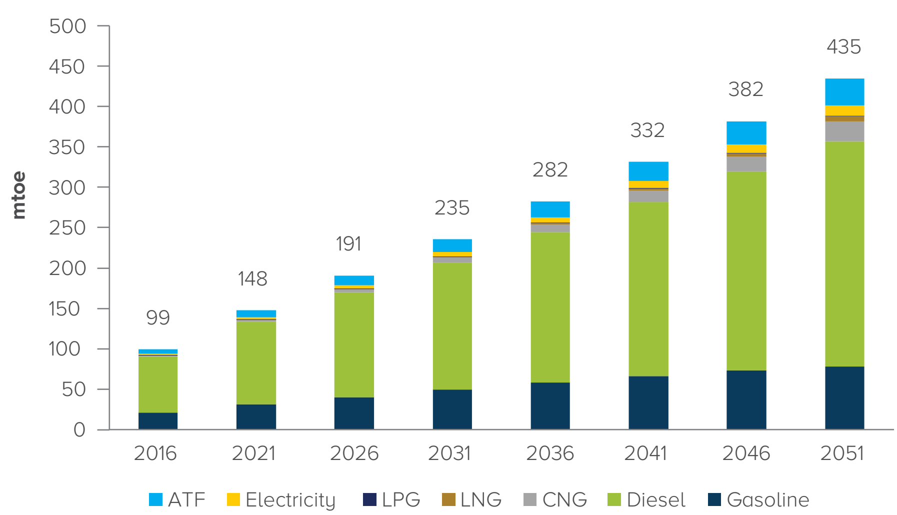


Figure 13: Total annual energy consumption from transport and fuel-wise break-up

Both energy consumption and emissions are skewed towards buses and M/HCVs, together these two segments account for 58% of the CO_2 emissions (Figure 14). The share of emissions is estimated to change over time. The contribution of buses to CO_2 emissions decreases to 16% by 2050, with passenger cars and taxis increasing their share. This reflects an increasing shift towards private vehicles in a business-as-usual scenario. M/HCVs accounts for around 38% of emissions in 2050, reflecting an extrapolation of the present shift away from rail to road. Emissions from aviation increase significantly in absolute terms but the overall share only increases to 8% in 2050.

CO_2 emissions are predicted to increase four-fold in the BAU scenario, from 282 million tonnes in 2016 to 1164 million tonnes in 2050. This reflects the trend of increasing energy consumption as well as the over-reliance on diesel and petrol. In terms of the whole energy system, the contribution of the transportation sector to total emissions is estimated to increase from 15% to 19% in 2050 (Figure 14). However, this reflects the BAU scenario for the other sectors considered as well. The industrial sector remains the highest contributor followed by the power sector. While the expected increase in emissions is a cause for concern, transport emissions in India in 2016 were much lower than in some developed countries, such as the US (1711 million tonnes) and China (851 million tonnes), and can be expected to remain lower up till 2050 (IEA 2020).

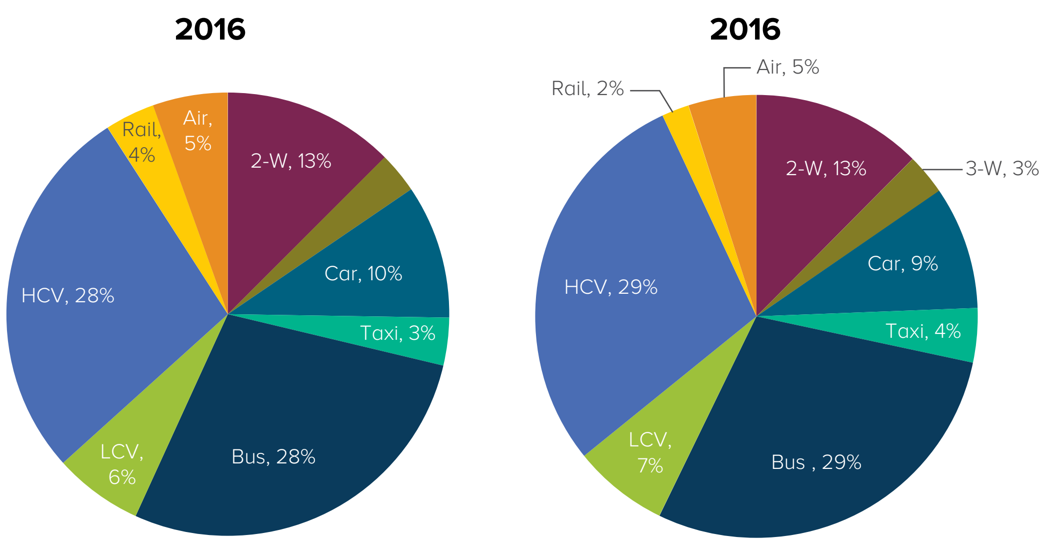


Figure 14: Segment-wise energy consumption and emissions

Comparison and validation of these results with previous studies are detailed in the annexure. TERI estimates are on the higher side due to the separation of urban and intercity operations and higher utilization for intercity operations, this has been highlighted in previous studies (Janaagraha Centre for Citizenship and Democracy 2020). The estimates are similar to the previous UNEP-DTU study, where the urban intercity separation was also done (Planning Commission 2013). The estimates are also slightly lower than previous TERI studies due to the updated GDP and utilization inputs.

Assessment of alternate pathways: Energy and emissions

Compared to the BAU scenario, the energy consumption and emissions are significantly lower in both decarbonization scenarios, even though the transport activity remains the same (Figure 15). The high electrification scenario (Scenario 1) was designed to understand the decarbonization potential of a rapid transition to EVs in the easier-to-transition segments. Our estimates suggest a significant reduction in overall energy consumption compared to the BAU scenario. In 2030, this strategy would lead to a 14% reduction in the total energy requirement; the benefit is even greater in 2050 with an estimated 26% reduction. This suggests that even a focus on electrification of easier-to-convert segments could yield large benefits.

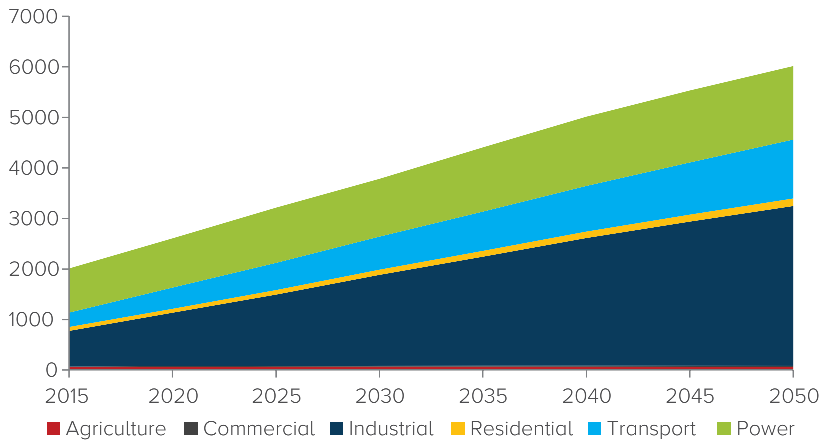


Figure 15: Annual CO_2 emissions from the overall energy system

However, the gains increase significantly when decarbonization of the hard-to-abate road sectors is assessed. Scenario 2 provides a 17% and 35% reduction in energy demand in 2030 and 2050, respectively. The reduction is higher after 2030 since it is assumed that uptake of alternate fuels in the heavy-duty segments takes off significantly only after 2030.

Despite the implementation of technology-based decarbonization strategies, diesel continues to remain a significant energy source in both scenarios (Figure 16 and Figure 17). This reflects the low base of low-carbon technologies, as well as the rapid growth expected in the Indian economy till 2050. The implementation of decarbonization strategies is nullified to a certain extent by the sheer rate of growth expected in the transport sector.

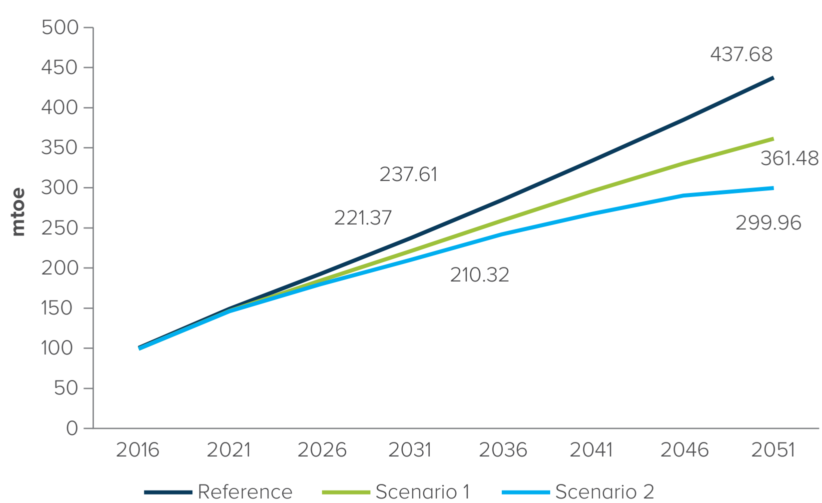


Figure 16: Scenario-wise annual energy consumption

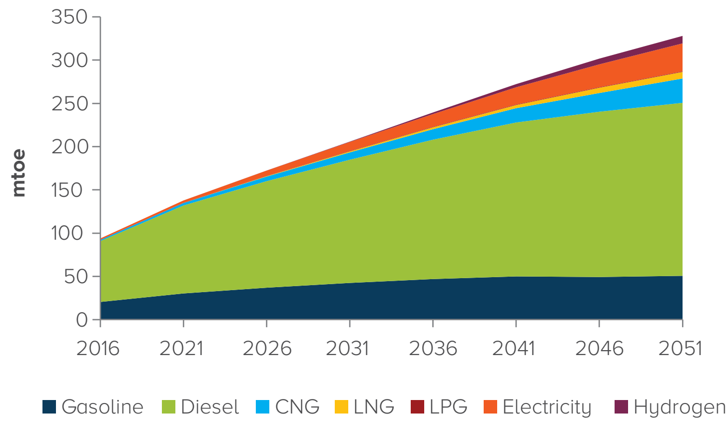


Figure 17: Annual energy consumption by fuel type in Scenario 1: electrification of easier-to-transition segments

In Scenario 1, diesel still makes up around 55% of the energy demand in 2050. In Scenario 2, diesel makes up 40% of the total energy demand in 2050. However, the growth rate in diesel consumption slows down around 2041 in Scenario 1. Scenario 2 is more encouraging, and diesel use from transport peaks around 2040, and reduces after this point as more freight movement occurs through electrified rail and HDVs switch to low-emission technologies. This highlights the importance of switching freight movement, especially long-distance freight, to low-carbon modes.

The reduction in energy consumption and switch to cleaner fuels translates into a significant reduction in overall emissions from the transportation sector (Figure 18). High electrification alone (Scenario 1) leads to an emission reduction of 9% and 22% by 2030 and 2050, respectively. Implementation of decarbonization options for hard-to-abate sectors (Scenario 2) leads to a reduction of 15% and 38%, respectively. The estimated contribution of the transport sector to emissions from the whole energy system reduces significantly but remains above 10%. By 2050, the contribution of transport reduces to 15% in Scenario 1, and further to 12% in Scenario 2.

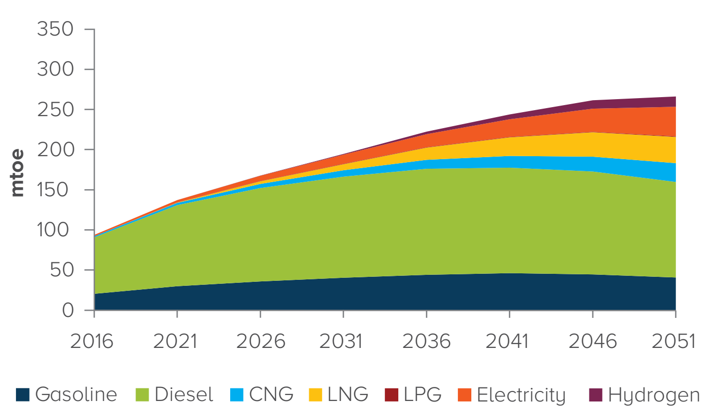


Figure 18: Energy consumption by fuel type in Scenario 2: Solutions for hard-to-abate segments

Table 6 shows the change in the estimated emission intensity of GDP from transport compared to the base year. Only a 15% reduction is observed in the BAU scenario, even in 2050. The reduction is greater for the scenario considering the electrification of easier-to-transition segments. However, significantly larger

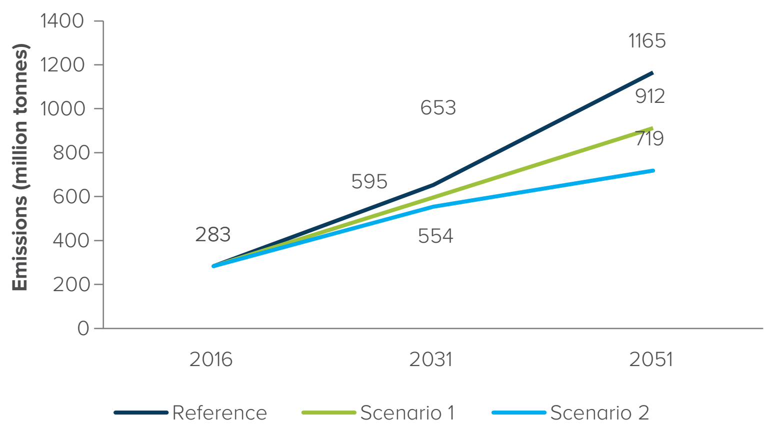


Figure 19: Scenario-wise CO_2 emissions from the transportation sector

gains are obtained when decarbonization options for the hard-to-abate sectors are considered, with the emission intensity declining by 20% in 2030 and by 48% in 2050 compared to 2016 in Scenario 2. Thus, the transport sector could play an important role in achieving India's overall NDC targets. However, this suggests that the focus will need to be on abating emissions from the heavy-duty road transport segments. It is also evident that given the present state of technologies, achieving NDC targets by 2030 will require a focus on near-term solutions, such as large-scale uptake of LNG trucks and a significant modal shift to rail.

Table 6: Change in estimated emission intensity of GDP from transport

	2015–16 (Tonne CO_2/1000 INR)	2030–31	2050–51
BAU	3.48	-2%	-15%
Scenario 1: Electrification of easier-to-transition segments		-13%	-30%
Scenario 2: Solutions for hard-to-abate segments		-20%	-48%

Source: *TERI analysis*

Emissions from the power sector

The power sector is modelled separately in the MARKAL while taking into consideration a mix of energy sources that evolves with time. To assess the impact of transport decarbonization on the power sector, it was assumed that the electricity demand from all the other sectors, except transport, remains the same in all scenarios. The increased demand from the power sector arises due to the direct increase in electricity demand from EVs, as well as the indirect electricity demand increase for producing other fuels, such as hydrogen.

Figure 19 paints a different picture compared to when only emissions are considered. Our estimates suggest that the sole focus on electrification in Scenario 1 leads to a slight increase in overall emissions when both sectors are considered. This is assuming that BAU is maintained in the power sector. Although the increase in emissions is very small (3%), this highlights the need to clean the electricity sector, if EVs are to be a successful decarbonization strategy.

The results for Scenario 2 are slightly more encouraging. Despite an overall increase in electricity demand, the combined emissions remain almost the same as the BAU scenario. In this case, the higher energy efficiency of rail movement counteracts the higher electricity demand from hydrogen production and EVs. This highlights the importance of the rail sector even if the penetration of renewables is not high. However, any technology-based decarbonization strategy for the transport sector will see a shift from traditional energy sources to electricity. For any of these strategies to be successful, rapid uptake of renewables in the power sector is essential.

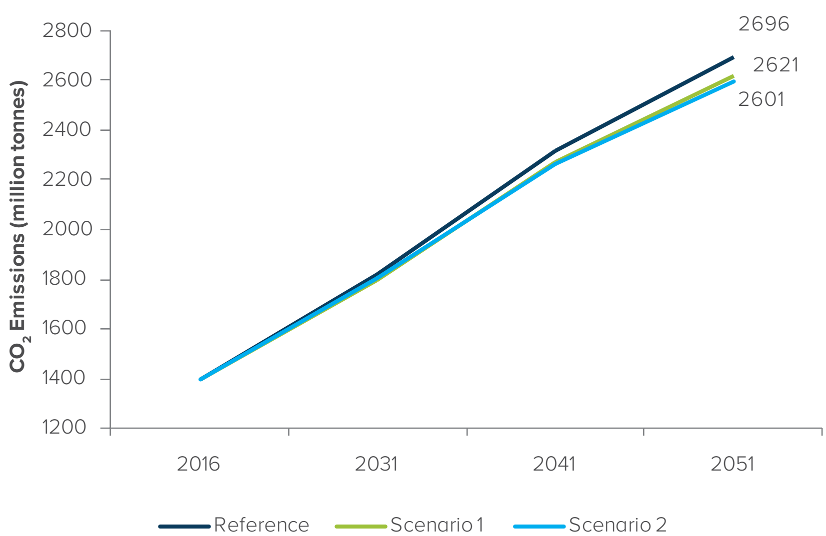


Figure 20: Scenario-wise combined emissions from transport and power sector

Assessment of alternate pathways: Energy security and infrastructure investment

The transportation sector is almost completely dependent on petroleum products, and the whole ecosystem is adapted to this. In contrast, existing low-carbon fuels are at a very nascent stage and will require a significant overhaul in infrastructure with significant financial implications. The infrastructure overhaul will be needed at all stages covering production, import, transport, and retail. Figure 20 provides a broad-level overview of the infrastructure requirements associated with different fuels.

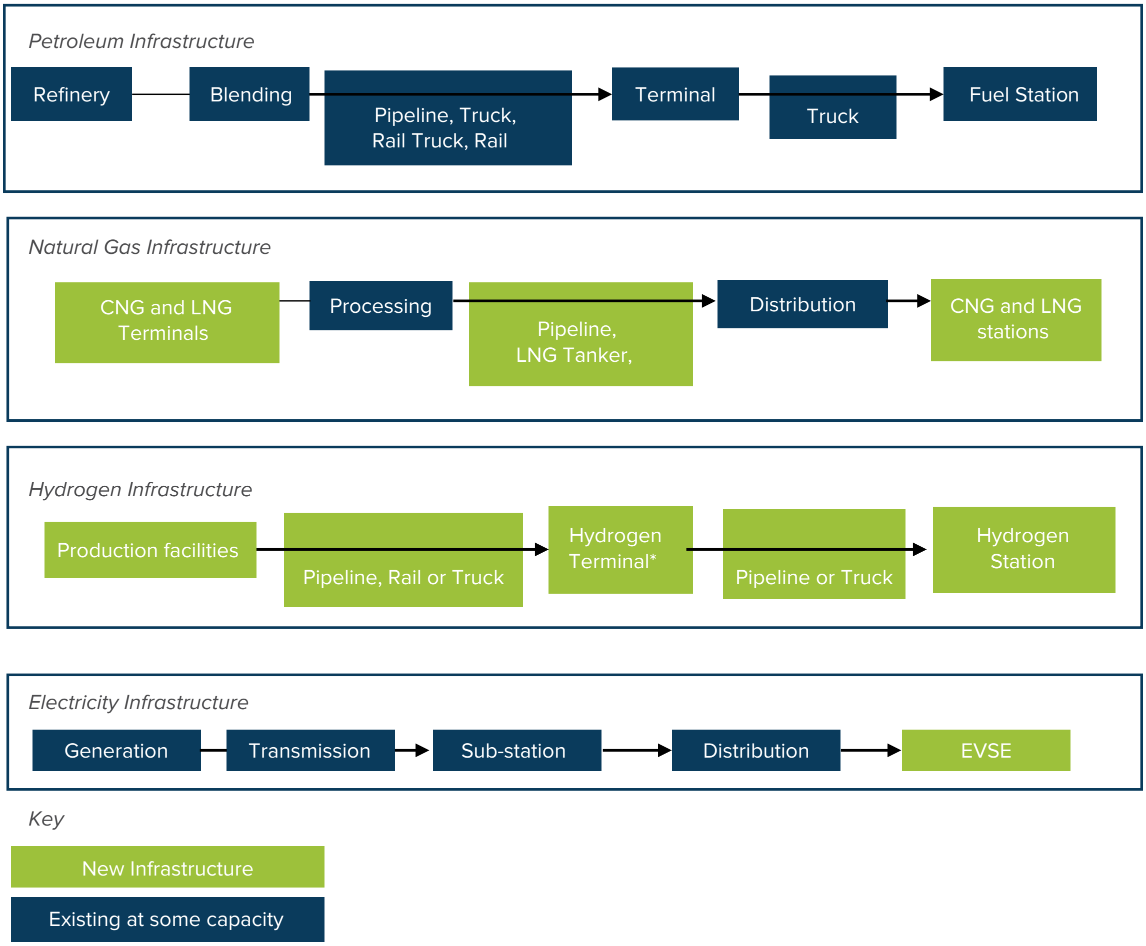


Figure 21: Infrastructure requirements for low-carbon fuels.

Energy security

The increased use of low-carbon fuels will require a significant change in the pattern of fuel production and imports. In the BAU scenario, the energy demand from petroleum products increases by 55% in 2030 and by 153% in 2050, which would require a significant increase in refining capacity as well as crude oil imports. India's crude oil import stood at 202.851 million tonnes during 2015–16, valued at ₹416,361 crores and made up around 21% of India's total imports, increased dependence on petroleum products for transport could see a significant increase in the import bill in the future (Ministry of Petroleum and Natural Gas 2018). A shift away from petroleum products will require a more diverse and complicated production and import mix

Presently, the electricity requirement from the transportation sector only accounts for around 1.2% of the total electricity consumption in the country (IEA 2018). In our high electrification scenario, electricity demand from transport increases threefold to 121.63 TWh by 2030 and further to 354.53 TWh by 2050. This would mean that the demand on the power sector from transport would increase significantly in the future. The switch to EVs will provide newer challenges for DISCOMS, as an increase in charging demand will increase the peak load—especially in densely populated urban areas. This could have significant implications on the cost of power procurement and network management (Das and Tyagi 2020).

The shift towards decarbonization will require increased use of natural gas as a transport fuel—both CNG and LNG demand is likely to increase. LNG is especially likely to be an attractive solution for hard-to-abate heavy-duty vehicles. In 2019, consumption of natural gas in India stood at 60 billion cubic meters, of which only 27 billion cubic meters were produced in the country (India Energy Statistics 2019). Presently, less than 2% of the demand for natural gas is from the transportation sector. However, in our decarbonization scenarios, the demand for natural gas from transport is estimated to grow at a high CAGR of 9.78% between 2020 and 2050, reaching 421 TWh by 2050. Given the limited availability of natural gas reserves within the country, this would require a significant increase in the import of both CNG and LNG. In addition to imports, significant public and private investment will be required to build storage and transport infrastructure, including LNG terminals and gas pipelines.

The current hydrogen demand in India is largely focused on the chemical and petrochemical sector. In our second scenario, increased penetration of FCVs in intercity buses and HCVs leads to hydrogen demand increasing from zero in 2020 to 149 TWh by 2050, reflecting a major increase in the share of transport in hydrogen use. This would require a major augmentation in hydrogen production capacity in India. As hydrogen is produced rather than extracted, the costs associated with production are always likely to be higher than natural gas. There is also a debate regarding whether the focus should be on producing blue hydrogen and then shifting to green hydrogen or whether the focus should be on directly enabling a shift to green hydrogen. The latter option is likely to be costlier but would lead to major environmental benefits and prevent technology lock-ins as the cost of green hydrogen productions come down. The key aspects influencing the production costs of green hydrogen include the cost of electrolyzers and the price of renewable energy. The cost of electrolyzers has declined in Europe and North America by almost 40% since 2014 and a recent study by BNEF suggests that renewable hydrogen could be produced for between $0.7 and $1.6/kg by 2050 in most parts of the world (Bloomberg New Energy Finance 2020). Investments would also be required in creating the right infrastructure for the transportation of hydrogen. However, it would require a major coordinated programme of infrastructure upgrades as hydrogen is incompatible with existing pipelines.

Retail refuelling infrastructure

The availability of retail fuelling stations is one of the biggest hurdles for consumer acceptance of low-carbon vehicle technologies. As of October 2020, around 71,843 petrol pumps were functioning in India, a further 78,000 are planned in the next few years. For alternate fuels to compete, a significant scale-up in retail fuelling infrastructure would be required. This would necessitate a major increase in the penetration of electric vehicle supply equipment (EVSE), hydrogen refilling stations, and natural gas dispensing stations. Some studies from the US suggest that coverage equivalent to 10%–20% of the existing petroleum-based stations would be a basic condition to support early markets for alternate fuels (Melaina 2003 and Nicholas, Handy, and Sperling 2004). However, sufficient coverage depends heavily on the population density of a region and traffic patterns, which are significantly different for India.

A recent study for the US compared the cost of setting up a typical gasoline station to other alternate fuels (Table 7) (Melaina,Sun, and Bush 2014). The capital costs associated with setting up an EVSE and hydrogen station were found to be threefold and sixfold higher, respectively, even in 2050. Thus, the cost of retail infrastructure for newer fuels is likely to be significantly more expensive in the short and long run. This translates into higher expenditure on establishing retail infrastructure for newer fuels compared to a petroleum-dependent pathway. Given that EVs have a lower range compared to their ICE counterparts, the density of EVSE in urban areas will also likely to be higher. Retail infrastructure will have to be established not only in urban areas but also on all major intercity routes, and specific guidelines will have to be developed for this as well.

Table 7: Fuel-wise estimate of costs associated with setting up refuelling stations

Capital Cost per 100 miles	Gasoline Station	CNG Station	Hydrogen Station	EVSE
2020	$2.14	$8.80	$13.31	$9.89
2050	$2.14	$7.78	$8.60	$6.09

Source: *Melaina, et al., 2013*

The new investment in fuel production capacity in the low-carbon scenarios is likely to be similar to the BAU scenario, given that the total energy requirement is lower. However, expansion of retail and transportation infrastructure would require large-scale investment to match the level of maturity associated with the gasoline infrastructure. Since the proliferation of retail infrastructure is largely guided by market forces, the increased investment in low-carbon infrastructure may not be compensated by the complementary reduction in gasoline infrastructure (Melaina, Heath, Sandor, et al. 2013). Major challenges associated with retail infrastructure include identifying appropriate spatial coverage and the deployment of sustainable business models. There is a need for increased research in this area to understand the influence of refueling infrastructure on consumer purchase decisions and the role of public–private partnerships in infrastructure planning and expansion.

Chapter 4:

FURTHER POLICY ACTIONS

Key Messages:

- Passenger activity is estimated to increase threefold by 2050.
- An even faster increase is seen for freight demand, around seven-fold.
- Dependence of the road sector and private modes of travel likely to keep increasing without significant interventions.
- Large-scale electrification can be expected in two-wheeler, three-wheeler, passenger cars, LCVs, and urban buses. High uptake of EVs in these segments is estimated to reduce CO_2 emissions by 22% by 2050.
- Hard-to-abate road segments account for more than 40% of the total transport activity, deep decarbonization depends on finding solutions for these segments.
- Enabling a transition to low-carbon fuels will require coordinated public and private investment at all stages of the supply chain.
- Emission reduction from technological transitions depend heavily on clean power sector.

The transportation sector in India is still at a nascent stage, motorization levels are on the rise, and emissions from the sector are much less than in similar countries. Our estimates suggest that this low base combined with economic growth means the transportation sector is likely to grow rapidly soon.

The results from the modelling exercise suggest that the present techno-centric policy actions have a significant potential to reduce emissions from the transportation sector. However, they are unlikely to be enough for deep decarbonization by 2050. The success of technological solutions is also heavily dependent on cleaning up the electricity grid. To achieve deep decarbonization these have to be combined with additional strategies relevant within the avoid, shift, and improve framework.

Further Actions for Deep Decarbonization by 2050

The following section highlights further actions that will be necessary for deep decarbonization. These strategies and actions were identified based on a policy review of global best practices as well as extensive stakeholder consultations

Expand the focus of EV policies

Despite pioneering incentives provided by the Central and State government, the uptake of EVs has not been up to the expected levels. Only around 5% of the FAME-II targets have been met so far. In addition to the demand and manufacturing incentives, some additional factors that have to be considered are listed below

State and central government

- A rating or incentive system for manufacturers based on the share of EVs in their production basket could lead to a wider range of EVs entering the market.
- Large-scale public investment to establish charging and swapping stations in public places. This would aid in creating a critical mass of infrastructure which would incentivize increased private investment.
- Awareness campaigns to highlight the benefits of EVs and provide practical information related to vehicle availability and charging infrastructure.
- Promote indigenous manufacturing of batteries by identifying long-term sources for raw materials and providing economic incentives.

Original equipment manufacturers (OEMs)

- Collaborate with potential customers to provide relevant EV models based on specific use cases.
- Identify risk-sharing mechanisms to distribute the risk of financing EVs due to uncertain resale value.
- Coordinate and share data with financing institutions to allow better evaluation of EV performance.

Foster innovation in low-carbon technologies for heavy-duty long-distance segments

There are no clear frontrunners for low- or zero-emission technologies for HDVs, intercity buses, and aviation. The future availability of technologies will depend upon the pace of innovation in potential technologies. Some steps for nudging innovation are stated below:

State and central governments

- Direct funding and support for research organizations involved in low-carbon technology research, such as fuel cells, battery technology, storage technology
- Establish courses in premier public institutions related to electric mobility and fuel cell technology
- Technology agnostic economic incentives for low-carbon trucks and buses could facilitate the uptake of the most cost-effective technologies. This would require providing subsidies/increasing taxes based simply on carbon emission, regardless of the technology

Original equipment manufacturers

- Increased funding for R&D of low carbon technologies
- Set targets for shifting away from the manufacture of diesel-based trucks and buses
- Engaging in international collaborations to import knowledge related to electric, hybrid, and fuel cell vehicles

Improve the efficiency of the logistics sector

The road logistics sector in India is characterized by obsolete vehicles and fragmented markets (RMI India NITI Aayog 2021). This leads to inefficient operations causing poor fuel economy, wasteful trips, and overloading. Streamlining logistics movement could enable significant emission reductions:

Central government

- Fuel economy standards and emission standards for trucks should be revised periodically. This should be done in consultation with truck manufacturers to ensure feasibility and timely implementation
- Ensure strict enforcement of standards through periodic monitoring of the on-road performance of trucks
- Introduce economic incentives to promote the scrapping of older trucks
- Improve the location of warehousing through better data collection related to the origin and destination points. This can be aided by leveraging existing data available from the GST e-way bill system
- Relook at biofuel policy. Identify enabling cost-effective pathways for second-generation biofuels

Private logistics operators

- Ensure optimal usage of truck capacity
- Periodic upgrade of obsolete vehicles
- Improve placement of warehouses to improve load factors and reduce empty trips
- Utilize larger sized trucks

Improve public transport services

The share of public transport in urban transport has been declining with people increasingly choosing to travel in private vehicles. The public bus system in most States consistently incurs operating losses and receives inadequate funding. This has led to constrained supply, obsolete vehicles, and poor customer satisfaction. Improving public transport systems can can dilute a shift towards private vehicles while also providing affordable and comfortable mobility to captive users.

Central government

- Increase fund allocation for bus procurement under centrally sponsored schemes such as JNNURM
- Earmark a certain proportion of fuel tax revenues for investment in public transport
- Increase subsidies for e-buses under the FAME-II scheme
- Encourage the use of PPP models by setting appropriate conditions in central schemes
- Encourage public sector banks to provide priority lending to State Transport Undertakings (STUs) at subsidized interest rates

State governments

- Prioritize increased budgetary provision for public transport
- Earmark a certain proportion of fuel tax revenues for investment in public transport

- Setup overarching body for administering urban transport which can coordinate actions of the multiple agencies involved at present
- Reduce or remove taxes on revenues of financially constrained STUs

State road transport undertakings

- Explore non-fare revenue generation such as land monetization and advertisement revenues
- Employ qualified staff for managing different operational aspects such as project management, contract management, route planning
- Provide training in PPP models to executive staff. Encourage adoption of relevant models with shared upfront costs to aid procurement
- Tie up with IT companies to provide better IT-enabled service for customers. This includes better scheduling, live data availability, online payments

Civil society

- Create a democratic demand for an accessible public transport system

Enable a modal shift to railways

The modal share of railways in India is much lower than most other countries with a developed rail system. An idea modal mix would require a significant increase in the share of rail in passenger and freight movement. However, the railway's infrastructure and marketing policies have failed to keep pace with the road segment due to paucity of investment and rigid administrative structure. Enabling modal shifts will require improving capacity to enable better transit times, especially for freight services. This will need to be combined with a more business-like approach to pricing and better marketing and outreach initiatives. Already significant investments are being done in terms of dedicated freight corridors, high-speed rail, track, and rolling stock augmentation. Some additional actions are listed below.

Central government

Increase investment in railways from 0.4% of GDP to 1.2% of GDP by 2030 as per NTDPC committee recommendations

Indian railways

- Expedite delivery times of infrastructure projects, especially the upcoming DFCs
- Improve operating ratio for passenger services, increase rates for loss-making services, and shut down lines with low utilization
- Establish more high-end long-distance passenger services which can compete with air transport
- Adopt a more business-like approach to freight tariff setting. Tariffs should be based on existing competition rather than internal principles
- Better implementation of station-to-station rates to decentralize freight tariffs and capture location-specific business

- Tie up with aggregators to create sustainable multi-modal business models for containers and parcel movement
- Improve terminal operations by incorporating global best practices related to terminal planning, mechanization, etc.

Control the growth of the motorization rate

Presently, the motorization rate in India is much below similar countries like Brazil and South Korea. Thus, this rate is likely to grow rapidly in the future. The growth in motorization can be curbed by reducing the need to travel, promoting non-motorized transport (NMT), and discouraging private vehicle usage.

Central government

Ensure implementation of NMT-related objectives highlighted in national-level urban policies through economic incentives, competitions, etc.

State governments

- Setup divisions within existing agencies with a mandate to improve non-motorized transport infrastructure
- Collect data regarding NMT use in cities
- Establish cycle lanes after assessing existing and potential utilization
- Strict enforcement of vehicle speed limits on routes with a high proportion of cyclists
- Establish pedestrian-only streets in different parts of the city
- Relocate/remove existing structures that impede pedestrian movement
- Awareness programme to highlight the benefits of non-motorized transport and address safety concerns
- Introduce relevant congesting pricing models in congested stretches in larger cities
- Institute parking taxes at certain highly congested areas or peak hours to help optimize parking spaces

Corporate sector

- Facilitate remote working arrangements where feasible
- Incentive-based schemes to encourage employees to use NMT for their commute
- Facilitate NMT by providing safe parking for bikes, and shower and changing facilities
- Provide subsidized transit passes, subsidized car-pooling services, and tax benefits for using mass transit modes

Plan to overcome overarching policy issues

Apart from the specific actions mentioned above, transition to a low carbon transport sector will require certain institutional adaptations. The shift away from the present gasoline-dependent system will also create ripple effects in other parts of the economy. Some of the issues that need addressing are highlighted here.

- **Establish institutions for holistic transport planning:** The transportation sector is at the beginning of a period of significant disruptions. However, the responsibility of implementing different strategies lies with different Central and State agencies. To coordinate actions for the transport sector, there is a need to have a specific institution within the Central and State Governments for transport planning. The National Transport Development Policy Committee Report (2014) had already put forward a road map for implementing this.

- **Coordinated investment in low carbon infrastructure:** Going forward, stricter criteria will need to be involved while assessing investment in transport infrastructure. There should be a focus on the lowest cost options while giving higher importance to investment in low carbon infrastructure. This will necessitate some judgments regarding the ideal modal mix as well as the segment-wise potential of alternate fuel options. Better coordination among different government agencies at the Central and State level will also be essential.
- **Increase transport planning and project execution capacity:** There is a lack of technical knowledge base for transport planning in government agencies. As a result, several policies and road maps often do not get executed on the ground. Lack of implementation of comprehensive mobility plans for cities is a good example of this. There is a need to either augment technical capacity within existing institutions or create separate institutions for transport planning.
- **Sustain revenues for investment in transport infrastructure:** Petroleum taxes contributed over 2% of GDP in the last decade. During 2010–17, on average 45% of India's union taxes (from customs and excise duties) and 26% of State taxes (from sales tax) were collected from the petroleum sector. Reduced consumption of these fuels could seriously affect government revenues. To ensure that the loss in revenue does not affect investment in decarbonization infrastructure, alternate sources of revenue will need to be established. Congestion pricing, limiting subsidies, and user access charges for using public infrastructure could be some of the strategies for mitigating this.
- **Differentiated planning for cities:** National-level policies and fund allocation must account for city-level differences in mobility patterns. Investment priorities should be in line with the particular city characteristics. This would require further empowering city-level transport agencies, both financially and in terms of technical capacity.

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ANNEXURES

Annexures

A1: Modelling Approach

In order to model transportation sector emissions, the study relied on econometric models, the TERI Transport Model (TERI TPTM) and TERI's MARKAL (MARKet Allocation) Model.

The TERI TPTM uses a bottom-up approach to estimate total volumes of passenger and freight transport demand for the period 2015–2050. The model is capable of assessing the cumulative impact of factors such as economic growth, population, and vehicle ownership to estimate transport demand from the transportation sector in India. The model assesses passenger and freight modes separately since the units of measuring passenger and freight movement are different. A further split has been made between rural/intercity and urban vehicles in order to reflect the differences in usage patterns. The model covers all major segments within the road, rail, and aviation sector (Figure 18). Within the road transportation sector, the segments considered are in line with the classification of vehicles followed by the Society of Automobile Manufacturers (SIAM). Some sub-segments are also considered within the broader segments, where relevant.

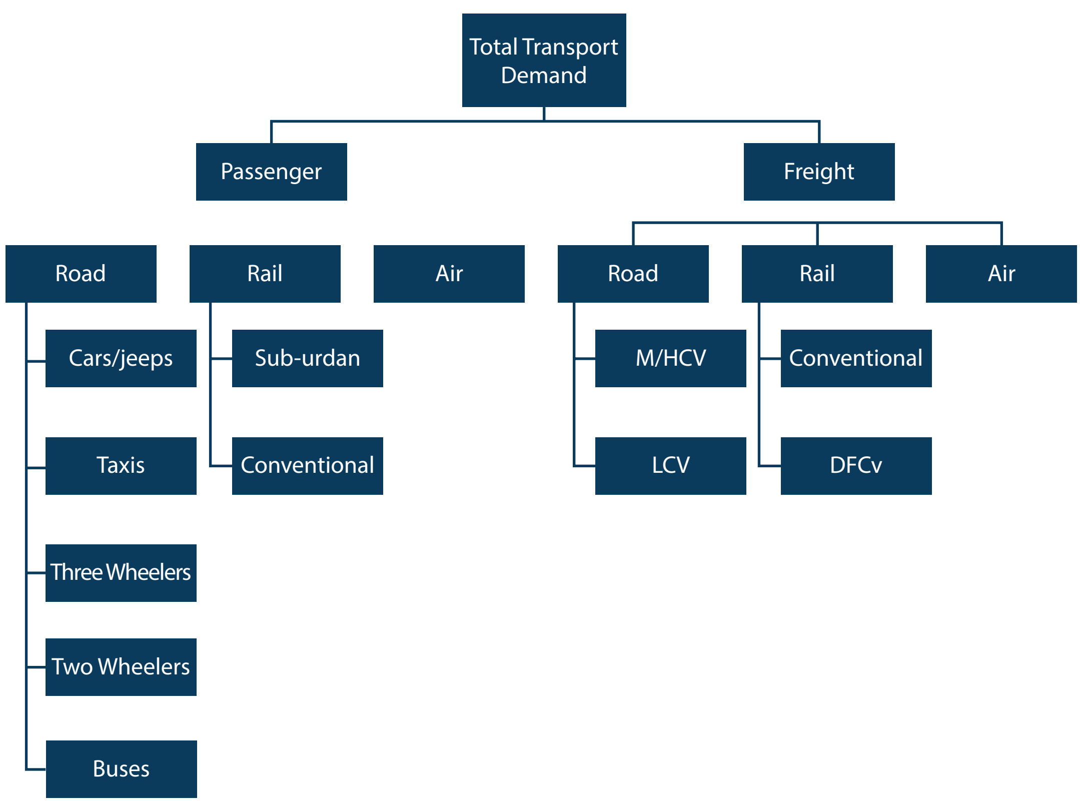

Figure A1: Segments considered for estimating transport demand

By taking into account the trend of growth in vehicles, the model first projects the future growth in number of vehicles. The actual registered vehicle data from the Ministry of Road Transport and Highways (MoRTH) is used till 2015–16, beyond which the population is extrapolated up to 2050 using econometric methods. The vehicle growth pattern in each segment is assumed to follow a S-shaped curve till it reaches a certain saturation level. The saturation levels are different for different segments, and estimated based on relevant literature as well as assumptions based on inputs from experts. The S-shaped curved is estimated using a logarithmic function, the parameters for which have been estimated by regressing the vehicle population against GDP, which is an accepted practice for estimating transport demand. For the rail and aviation segments the BPKM and BTKMs are taken directly from Railway Board and Directorate General of Civil Aviation (DGCA) data up till 2015-16 and extrapolated further up till 2050.

Further, the actual travel demand is estimated by taking into account vehicle activity patterns, such as daily utilization, mileage, occupancy, load factors, etc. (Figure 19). The activity data is estimated separately for each vehicle segment as well as by technology. The inputs are obtained from published literature, estimates from survey data, and assumptions based on stakeholder consultations.

$$TKM_i/PKM_i = TA_i = V_i * FT_i * VU_i * P_i$$

where:

TKM_i/PKM_i= Tonne kilometre/passenger kilometres by vehicle type i

VU_i = Vehicle Utilization

TA_i = Transport activity by vehicle type i

FT_i = Share of fuel technologies

V_i = On-road stock of vehicle i

P_i = Payload/Occupancy

Source: Based on Pal, et al., 2015

Figure A2: Bottom-up estimation of travel demand for different vehicle types

Different types of vehicles use different types of fuels and have different efficiency levels. An important step in the modelling process is segregation of the vehicle stock by fuel technology types. For each segment, different market shares for relevant technologies are considered, these market shares are made to vary between the different scenarios in order to understand the implications of penetration of alternate technologies.

The various categories of energy service demand, so calculated, are fed into the MARKAL model. MARKAL is a bottom-up, dynamic, linear-programming model that depicts both the energy supply and demand sides of the energy system. MARKAL interconnects the conversion and consumption of energy carriers. This user-defined network includes all energy carriers involved in primary supplies, conversion and processing (for example, power

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For the purpose of this study, only the transportation sector of the MARKAL model has been revisited to assess emissions based on the demands estimated from the TERI TPTM model for different scenarios.

Table A1: Scenario-wise market share of different technologies

Strategy	Target	Reference			Decarbonization scenario 1			Decarbonization scenario 2		
		2020	2030	2050	2020	2030	2050	2020	2030	2050
Electrification of road transport	% of EVs in total 2-W	1%	4%	12%	1%	30%	60%	1%	30%	75%
	% of EVs in total 3-W	9%	14%	25%	9%	40%	75%	9%	40%	75%
	% of EVs in total cars	0.1%	2%	6.2%	0.1%	10%	45%	0.1%	20%	45%
	% of EV in total LCVs	0%	3%	8%	0%	30%	50%	0%	17%	50%
	% of EVs in total buses	<1%	1.5%	3%	<1%	5%	15%	<1%	5%	15%
	% of EVs in intercity HCVs*	0%	0.5%	2%	0%	1%	5%	0%	1%	5%

Strategy	Target	Reference			Decarbonization scenario 1			Decarbonization scenario 2		
		2020	2030	2050	2020	2030	2050	2020	2030	2050
Alternate fuels in road transport	% of FCVs in intercity HCVs	0%	0%	0%	0%	0%	0%	0%	8%	20%
	% of LNG in intercity HCVs	0%	<1%	3%	0%	1%	3%	0%	2%	13%
	% of FCVs in intercity buses	0%	0%	0%	0%	1.5%	4%	0%	1.5%	20%
	% of LNG in intercity buses	0%	0%	0%	0%	<1%	3%	0%	5%	20%
	% share of railways in passenger movement	13%	12%	11%	13%	14%	16%	13%	16%	23%
	% share of railways in freight movement	27%	25%	22%	27%	28%	30%	27%	32%	45%

***only for HCVs below 16.2 tonnes**

Model Validation

Figure 26 shows the service demands from this study compared to previous works. All these models use different assumptions related to saturation levels and utilization parameters which lead to the difference. The estimates from TERI are on the higher side compared to most of the other sides, only the BPKM estimates from the UNEP-DTU study are higher. The demand for freight transport from our study is significantly higher than the others. The major reason for this is the separate inputs taken for urban and inter-city vehicles, a segregation not explicitly accounted for in other models. This discrepancy and reason have already been pointed out in a previously published multi-model study. The UNEP-DTU estimates are the closest to our estimates, this study also separated the demand according to urban and intercity movement. Another reason for the increased demand is because this study looks at the aviation and rail sectors as well, which is not the case for all the others.

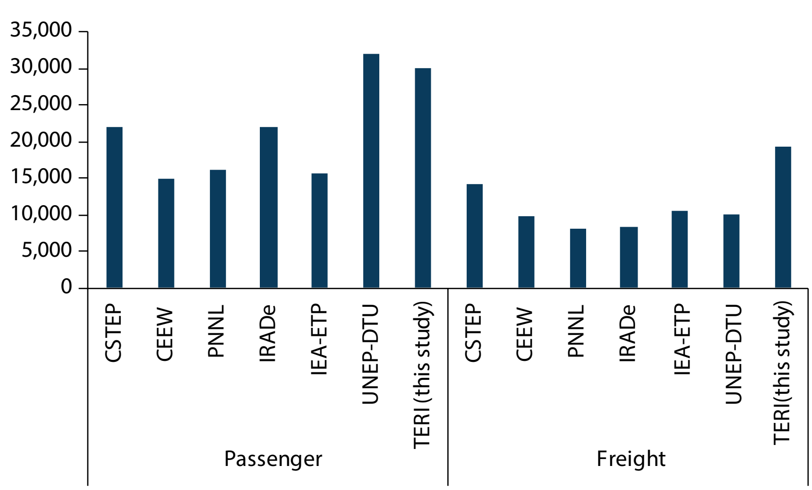

Figure A3: Comparison of estimated service demands in 2050 from different studies

The emissions estimate from our model were compared with other relevant publications (Figure 26). The baseline estimates for 2016 from our model track well with the estimates from the *3rd Biennial Update Report (BUR 3)*, our estimates higher by only 7% from *BUR 3*. Beyond the base year, the estimates are similar to available estimates from NITI Aayog and the Centre for Study of Science, Technology and Policy (CSTEP) and slightly higher than the estimates from the Council on Energy, Environment and Water (CEEW). Beyond the year 2030, the growth in emissions from the TERI model are more rapid than other publications, this likely reflects the conservative estimates related to electrification and modal shift in the reference scenario. The IEA-ETP (2017) estimates are much higher than our estimates at all time points, eventually reaching 1855 $MTCO_2$ 2050. However, their estimates included the complete well-to-wheel emissions.

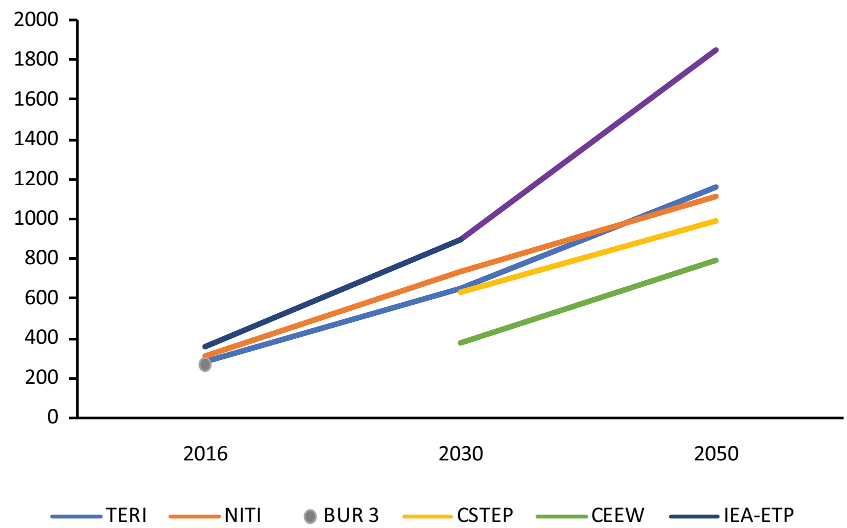

Figure A3: Comparison of estimated service demands in 2050 from different studies

A2: Review of Central and State Policies

Road Transport

Decarbonization of road transport sector has received a significant policy attention at both national and state level. Four broad strategies have been identified for the decarbonization of this sector—modal shift, vehicle efficiency improvements, electrification of vehicles, and use of alternate fuels.

- *National Biofuel Policy 2018:* The policy aims to achieve 20% blending of biofuels with the fossil-fuel-based fuels by 2030.
- *Auto Fuel Policy 2015*: The Auto Fuel Policy provides a road map for adoption of improved vehicular technology and fuel quality in order to reduce vehicular emissions from motorized vehicles. The policy mandated a shift to BS-IV standards by 2017 and further leapfrogged to implement BS-VI standards by 2020.
- *Vehicle Fuel Efficiency Program*: In April 2017, the Ministry of Road Transport and Highways (MoRTH) came up with first set of fuel economy norms for light duty vehicles (LDVs) in passenger segment. These standards are based on corporate average fuel economy (CAFÉ) norms and define the targets in terms of fuel consumption in litre/100 km. In order to ensure compliance, these standards are converted into CO_2g/km for petrol, diesel, liquefied petroleum gas (LPG) and compressed natural gas (CNG) passenger vehicles with gross vehicle weight (GVW) under 3.5 tonne. The policy will lead to continuous reduction

in CO_2 emissions through setting the efficiency standards for new vehicles at 130 g/km in 2017 and 113 g/km in 2022 for every automaker (TransportPolicy.net).

- *National Electric Mobility Mission Plan*: The plan aims to accelerate the adoption of electric vehicles (EVs) in India through increased investment in technology development and provision of subsidies. For the same, the Department of Heavy Industries (DHI) has launched Faster Adoption and Manufacturing of Electric Vehicles (FAME) subsidy scheme. This scheme aims to increase the penetration of EVs in India. Thus, focus has been on four key features: demand creation, technology development, pilots, and charging infrastructure. The scheme is launched in two phases for a period of 2 years. Under Fame 1 scheme, a total of 2.8 lakh vehicles were given incentive of about Rs. 359 crores (Fame, 2020). The second phase has an outlay of Rs. 10,000 crore and targets to support 7000 electric buses (e-bus), 5 lakhs electric three wheelers (e-3W), 55,000 electrics four-wheeler passenger cars (including strong hybrid) (e-4W), and 10 lakhs electric two wheelers (e-2W).

Further, FAME II scheme was rolled out in the year 2019 with a total budgetary support of Rs 10,000 crore. The scheme aims to promote uptake of EVs in commercial vehicle segment by providing demand incentives. This in turn will help in increasing the usage of public and shared transport services. Additionally, creation of charging infrastructure is also one of the key agendas of this policy.

- *State level EV policies:* Apart from the national incentives, 27 states have issued their EV policy with an aim to uptake manufacturing and adoption of EVs. Some of the policy provisions are mentioned in the table below:

State EV policy	Objectives
Karnataka Electric Vehicle and Energy Storage Policy, 2017	Aims to develop Karnataka as EV manufacturing hub and to attract investments of Rs. 31,000 crore and create employment opportunities to 55,000 persons both from supply and demand side. It also aims to create conducive environment for EV transition (GoK, 2017).
Delhi Electric Vehicle Policy, 2018	Aims to improve Delhi's air quality through transport emission reduction such that battery electric vehicles (BEVs) will contribute to 25% of all new vehicle registrations by 2023. It supports measures for job creation in the EV space. (Delhi Government, 2018).
Uttar Pradesh EV Policy, 2018	Aims to create employment opportunities both from supply side and demand side thereby developing conducive environment for EV transition.
Draft Kerala EV Policy	Promotes shared mobility and clean transportation, pollution reduction, energy efficiency and conservation in order to create an ecosystem for EV component manufacturing. The policy aims to create enabling ecosystem—skilled manpower, infra, R&D, regulations and initial volumes through govt. programmes.
Maharashtra EV and Infrastructure Policy- 2018	Aims to make Maharashtra a leader in EV manufacturing and use and thereby generate new employment opportunities.
Draft Telangana EV Policy	Target to attract investments worth US$ 3 billion and create employment for 50,000 persons by 2022 through EV manufacturing and charging infrastructure development.
Andhra Pradesh EV Policy, 2018	Aims to make Andhra Pradesh a global hub for EV development and manufacturing thereby attracting EV manufacturers and promote EV innovation and R&D through grants and venture funds, industrial park development, skilled workforce. The policy promotes EV usage in cities and also enables investment in charging/battery swapping infrastructure.

- *Increased focus on natural gas for transport*: Both CNG and liquefied natural gas (LNG) have been seen as feasible low carbon options for the transport sector. Overall, it is envisaged that the share of natural gas in the primary energy mix would reach 20% till 2030, up from 10% in 2010. The Government of India (GOI) recently unveiled a Natural Gas Infrastructure Development Plan to set up 10,000 CNG stations over the next 10 years.

  The 2017 Amendment to the Central Motor Vehicles Rules, 1989, to include LNG as a fuel for automobiles was an important first step for introduction of LNG vehicles. Additionally, India is set to see investments to the tune of around Rs. 10,000 crores in three years to create infrastructure for using LNG as a fuel for long-haul transportation. This will include the setting up of 1000 LNG stations.

- *Acceptance of hydrogen as a transport fuel*: Proposed amendment to the Central Motor Vehicles Rules, 1989 to include safety standards for fuel cell vehicles suggests an acceptance of this technology as a future solution. NITI Aayog has also recommended the use of H-CNG by utilization of the existing piped-gas infrastructure in Delhi. It has further recommended that H-CNG be notified as an automotive fuel, standards for its usage be issued by the Bureau of Indian Standards (BIS), and clearance for H-CNG storage cylinders on vehicles be issued by the Petroleum and Explosives Safety Organisation. The use of H-CNG has already been tested as part of a trial run in buses in Delhi. The common consensus seems to be that fuel cell vehicles could be a long-term solution for heavy duty vehicles where the battery requirements for EVs may be counterproductive.

Railways

Decarbonization of the railways sector has received appreciable attention. The Railways set an ambitious target of achieving net zero by 2030. For this purpose, IR has taken a number of initiatives towards reducing GHG emissions from their operation, both in terms of train movement and infrastructure. Electrification, improving the energy efficiency of trains, and green certification are some of the major steps, highlighted earlier. Railways will be focusing mainly upon reduction of carbon emissions and at the same time improving energy security by reducing fossil fuel imports and increasing the capacities of renewables.

The Indian Railways had earlier announced its 1 GW solar target in the year 2015 and had already achieved an installed capacity of approximately 37 MW of wind and 16 MW of solar across all the railway operations up until March 2017. It is already on track to achieve 5 GW by the year 2025, in which around 1.1 GW will come from the rooftop projects and remaining from utility-scale projects.

Aviation

The International Civil Aviation Organization came up with Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in October 2016 with the aim of decarbonizing civil aviation starting from 2021. Under the scheme, countries can voluntarily join to reduce the CO_2 emissions from aviation till 2027, after which, the decarbonization targets are binding to all the members. Despite being the member of Paris Agreement, India declined to sign CORSIA agreement. India has proposed to determine the country's baseline aviation emission levels based on Revenue tonne-kilometre of its nationals traveling across the world (Sinha, 2019). However, India will join the agreement from 2027, that is, from the mandatory phase.

India has also launched the Indian Ocean Strategic Partnership to Reduce Emissions (INSPIRE) in 2011 with the aim to improve the efficiency and sustainability of aviation. The mentioned partnership is between vAirport Authority of India, Air Service Australia, Dubai Airports, and many other organizations (Inida GHG Program, 2015).

Though India has not joined CORSIA agreement at the moment, Indian aviation sector is has taken some steps towards offsetting emissions from aviation. Cochin is the first solar-powered airport with the capacity of 12 megawatt. Currently, 38 airports in India have solar power systems installed or are in the process of installing. The peak installed capacity will be 124.5 MW and 77.6 MW has been commissioned to the date (Anon., n.d.). Among all these airports, Puducherry airport is the first 100% solar-powered airport of India (Gupta, 2020). Airports are also adopting green designing principles to offset the GHG generation.

Decarbonization of aviation sector is difficult, but options for low-carbon fuel and biofuels are being tested with differing levels of success. Aviation fuels made from biomass and biowaste help to reduce the total carbon emission of operational phase. Recent research in the field says that among the developed sustainable aviation fuels, synfuels are very promising and have no direct CO_2 emission (Adami, et al., 2021). National policy on biofuels directs and accelerates the use of wastes and energy crops to generate the biofuels. Also, the government is considering a grants programme for cellulosic ethanol facilities utilizing crop residues (ICCT, 2019).

Other Policies

- *Urban Green Mobility Fund*: Ministry of Housing and Urban Affairs (MoHUA) unveiled this policy in 2017. The fund aims to promote non-motorised transport, bike sharing and improve bus systems in Indian cities. The fund was setup to have a total fund of INR 80,0000 crore which would be distributed to cities according to their ranking in the 'Green Mobility Challenge', where cities have to pitch their urban mobility plans.
- *National Transit Oriented Development (TOD) Policy*: formulated by MoHUA, the policy aims to provide guidance for TOD to be a viable solution for many urban issues, including mobility. The policy aims to promote city densification, mass transit corridors, non-motorised transport Infrastructure for walking and cycling to transport stations, development of street networks in the influence zone of transit corridors, multi-modal integration and effective first and last mile connectivity. However, the policy remains as a guidance and while some cities have taken a cue from these guidelines, large scale implementation has been scarce. Stakeholder consultations

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