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Pathways to decarbonize India's transport sector: Scenario analysis using the Energy Policy Simulator

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CONTENTS

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HIGHLIGHTS

- Realizing India's current climate commitments in the near term (by 2030) and long term (by 2070) would require effective decarbonization strategies in all the key economic sectors, including transport.
- Although India's Long-Term Low-Carbon Development Strategies include overarching strategies for the transport sector, it would be prudent for policymakers to quantify the decarbonization potential of various strategies for target setting and strategic implementation in a time-bound manner.
- This working paper presents the decarbonization potential of three strategies—fuel economy improvements, electrification, and modal shift—through 2050 using the India Energy Policy Simulator, analyzed based on their low- and high-ambition levels.
- When implemented in isolation, the electrification strategy provides the highest carbon dioxide (CO_2) emissions reduction potential by 2050 (57 percent) compared with the business as usual (BAU) scenario, followed by fuel economy improvements (21 percent) and modal shift (18 percent).
- Implementing fuel economy, electrification, and modal shift strategies simultaneously at their highest ambition level results in a 71 percent reduction in CO_2 emissions and fossil fuel consumption by 2050 compared to the BAU scenario.

EXECUTIVE SUMMARY

Context

India aims to reduce its emissions intensity of gross domestic product by 45 percent from 2005 levels by 2030 and also achieve net zero by 2070. It also has an overarching energy sector target, which is to increase the share of non-fossil power capacity to 50 percent by 2030. However, currently, the transport sector, which accounted for 14 percent of total energy-related carbon dioxide (CO_2) emissions in 2020, lacks an emissions reduction roadmap or targets (Kumar et al. 2022). Analyzing the mitigation potential of various strategies and developing a decarbonization roadmap for India's transport sector will play a pivotal role in achieving its economy-wide targets committed through Nationally Determined Contributions (NDCs) under the Paris Agreement.

About this working paper

India's Long-Term Low-Carbon Development Strategy (LT-LEDS), submitted in November 2022, highlights key strategies such as electrification, fuel efficiency improvements, and a modal shift to public transport for passenger transport and toward railways for road freight. An integrated assessment of the decarbonization potential of each of these strategies and their cumulative impact is required to prioritize effective low-carbon transport policy packages. This working paper presents the decarbonization potential of each of these strategies by disaggregating them into policy levers, under varying time frames and intensities. This assessment is based on the India Energy Policy Simulator (EPS), an open-source systems dynamics model that allows users to develop scenarios for varying time frames (i.e., by 2030, 2040, and 2050) and ambition levels, and assess their impacts on output parameters such as CO_2 emissions and energy reduction. The findings are based on the simulation and inputs from expert stakeholder consultations.

The socioeconomic implications of the strategies are outside the scope of this working paper. The results presented using the simulation are limited to aggregated outcomes at the national level and do not capture the distributional impacts of those outcomes across different regions or population subgroups, such as socioeconomic, gender, or age groups.

Key findings

With existing policies, that is, in the BAU scenario, the transport sector in India will still be largely reliant on fossil fuels until 2050. The consumption of fossil fuels such as liquified petroleum gas (LPG), diesel, and petrol is expected to quadruple over the next three decades. Such consumption will be driven by passenger travel demand, which is estimated to triple between 2020 and 2050, and freight travel demand, which is likely to increase seven times during the same period.

At high ambition level for all the three strategies (fuel economy standards, electrification, and modal shift), stringent fuel economy standards can reduce CO_2 emissions, lowering total emissions by 40 percent from BAU values by 2030. Enhancing fuel economy standards for freight light-duty vehicles (LDVs) and freight heavy-duty vehicles (HDVs) could further reduce CO_2 emissions by 44 percent (By enhancing the policy levers of freight LDVs and HDVs from 60 percent to 90 percent) from BAU values.

When all the three strategies are implemented in high ambition, the modal shift at a high-ambition level results in a total CO_2 emissions reduction of approximately 33 percent from BAU levels by 2030. The shift of road freight demand to railways would require continuous investments in infrastructure improvement and last-mile connectivity (Sinha et al. 2021). Other studies also highlight that the government would have to implement a few soft interventions to enable a behavioral shift toward public transport, such as awareness campaigns; increased comfort, both in vehicles and in stations; monetary incentives; enhanced and reliable last-mile connectivity services; and smartphone applications for easy access to ticketing and route information (Zarabi et al. 2021).

Electrification accompanied by grid decarbonization (55 percent renewables by 2050) has the highest decarbonization potential in the medium and long term by 2050. This is driven by the electric vehicle (EV) sales mandate for cars, buses, two-wheelers, three-wheelers, and freight LDVs and HDVs, whose total contribution to overall CO_2 emissions reduction in the transport sector increases exponentially from 25 percent in 2030 to 47 percent and 65 percent in 2040 and 2050, respectively, when all three strategies are implemented at high ambition. This scenario also includes factors such as aggressive deployment of charging infrastructure, introduction of feebates, EV subsidies, and a reduction in range anxiety for EV models.

Modal shift is the least-cost policy with the highest net savings at the lower end of its modeled cost estimates, and the EV sales mandate provides the highest carbon dioxide equivalent (CO_2e) emissions reduction. The shifts of road passenger demand to public transport and of road freight to railways provide significant annual CO_2e abatement, with savings of about INR 12,118 per tonne of carbon dioxide equivalent (tCO_2e) abated. The EV sales mandate is most effective in terms of CO_2 emissions reduction, with an annual abatement potential of 121 $MtCO_2e$.

Deep decarbonization of the transport sector is possible and will lead to a CO_2 emissions reduction of up to 71 percent below BAU values by 2050. This scenario is produced by using the highest ambition for all three strategies, that is, fuel economy standards, electrification, and modal shift. At low-ambition values for these three strategies, the India EPS produces scenarios with 32 percent CO_2 reduction in transport emissions and 30 percent reduction in fossil fuel consumption by 2050.

Policy implications

The decarbonization of the transport sector in India can be driven by implementing least-cost policies. The simulation suggests that the modal shift to low-carbon transport for both the freight and passenger segments is the most cost-effective policy in the long term, with an approximate savings of INR 12,118 per tCO_2 abated. Electrification across passenger and freight segments provides the highest emissions reductions, highlighting the need to include sales mandates and other targets for electric freight in national level policies.

Decarbonization of the transport sector needs to be supported by clean electricity generation sources. The ambitious electrification targets in the transport sector need to be supported by the decarbonization of electricity generation. The analysis suggests that all three strategies in the transport sector when implemented at the highest ambition level contribute to a 71 percent reduction in transport sector greenhouse gas emissions by 2050 compared to BAU values. Implementing an additional policy with a carbon-free electricity standard where 75 percent of electricity is sourced from renewables results in a 75 percent reduction by 2050 compared to BAU values.

Taxes on fossil fuels enable deeper emissions reductions by complementing fuel economy standards. Fuel economy standards improve new vehicle efficiency, but in the absence of complementary emissions tax policies, some of this gain may be offset by increased vehicle use due to the cheaper cost per mile of traveling. This "rebound effect" phenomenon is exacerbated if fuel is subsidized rather than taxed (Zheng et al. 2022).

Modal shift propels a significant reduction in road passenger demand. Whereas passenger demand increases with electrification or improved fuel economy, the modal shift toward public transport reduces passenger demand for taxis, cars, and sport-utility vehicles (SUVs) by 35 percent each, by 2050. However, for public transport to produce a modal shift, it must satisfy user needs in terms of both physical factor attributes (attributes that can be directly measured, such as public transport frequency and availability) and perceived factor attributes (attributes that are measured through user feedback, such as comfort and safety) (Urbanek 2021).

INTRODUCTION

India's climate commitments

Climate science is clearer than ever before. The world needs to reduce greenhouse gas (GHG) emissions by 45 percent by 2030 compared to emissions projections under current policies, to avoid a global climate catastrophe. Moreover, emissions must continue to decline after 2030. This would require sectoral transformation toward zero GHG emissions across all sectors, such as energy, land use, buildings, industry, and transport, where climate action needs to rapidly scale and accelerate in order to limit global warming preferably below 1.5°C (UNEP 2022).

India recognizes the climate threat and is taking various steps to mitigate its GHG emissions. India submitted its updated first Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2022, where two quantifiable targets (i.e., 45 percent emission intensity reduction of its gross domestic product [GDP] by 2030 and 50 percent cumulative electric power installed capacity from non-fossil-fuel-based resources by 2030) were updated with the long-term aim of reaching net zero by 2070 (Government of India 2022). India also submitted its Long-Term Low-Carbon Development Strategy at the 27th UN Climate Change Conference, COP27 (MoEFCC 2022). All these international commitments and targets would require emissions reduction from all the key economic sectors, including the transport sector.

India is a signatory to the Accelerating to Zero Coalition, "a global platform aimed at supporting zero-emission transportation policies and leadership" and is committed to accelerated proliferation and adoption of zero-emission vehicles (ICCT 2023). It also has a target of achieving 30 percent EV sales penetration by 2030 and has launched the National Mission on Transformative Mobility and Battery Storage to support local EV component manufacturing (Patnaik et al. 2021; PIB 2023a).

Decarbonizing the transport sector: The need for this study

The growth of the transport sector in India and its subsequent contribution to carbon emissions is at an important intersection. The sector accounted for 14 percent of total energy-related CO_2 emissions in 2020, 90 percent of which was driven by road transport, which remains the most carbon intensive (Kumar et al. 2022). Out of this 90 percent, two-wheelers contributed about 16 percent, cars about 25 percent, buses 9 percent, freight light-duty vehicles (LDVs) 8 percent, and freight heavy-duty vehicles (HDVs) 45 percent (the highest). Railways, aviation, and waterways contributed 6 percent, 3 percent, and 1 percent of energy consumption, respectively. The transport sector's energy consumption and related CO_2 emissions doubled in 2020 since 2010 and are likely to quadruple in the next few decades under the BAU scenario. With just a 5 percent share in total registered vehicles, medium- and heavy-duty trucks contribute 40 percent of total vehicular emissions and remain hard to abate (MoRTH 2021). Further, trucks in India have low productivity and utilization, running an average of 300 kilometers (km) in comparison to the global average of 500–800 km per day. They also have empty running rates as high as 40 percent (Sinha et al. 2021), indicating more travel and emissions to move the same volume of goods.

With the number of cars per 1,000 people more than doubling in a decade from 2007 to 2017, from 8.99 to 23.35, possibly due to the increase in per capita income and the availability of cars to cater to different income groups, the rapid growth of private vehicles is likely to remain a key source of GHG emissions and vehicular air pollution in the near and longer terms (Verma 2015; MoRTH 2019). This is also accompanied by the declining share of low-carbon modes for passenger and transport. India has only 1.3 buses for every 1,000 people (MoRTH 2020), which is much lower than that of other developing countries such as Brazil (4.74 per 1,000) and South Africa (6.38 per 1,000) (Mookherjee and Mitra 2022). A bus has a lower carbon footprint (97 grams of carbon dioxide equivalent [gCO_2e] per passenger-km on average) than a car (170 gCO_2e per passenger-km on average), depending on fuel use, efficiencies, and occupancy (Ritchie and Roser 2023). The share of bicycle trips decreased by an average of 20 percent in the two decades between 1980 and the 2000s (Monga and Sadhukhan 2023), and walking trips decreased by 10–30 percent during the same period (Tiwari et al. 2016).

With respect to freight, only a meager 17.5 percent of freight traffic is transported by the railways. While freight tonnage increased by 75 percent, the modal share of rail freight decreased by 50 percent between 1990 and 2015 (Aritua 2019). This can be attributed to insufficient capacity and overutilization of existing routes (Sinha et al. 2021). Rail freight emits an average of 9.5 gCO_2 per tonne-km (WRI India 2015), depending on the level of electrification and the grid energy mix, whereas road freight emits 60–110 gCO_2 per tonne-km (Kaack et al. 2018), depending on the size of the vehicle.

Given these trends, decarbonizing the transport sector remains a crucial element in the overall strategy for meeting India's medium- and long-term GHG emissions reduction commitments. India currently does not have a decarbonization roadmap or GHG mitigation targets for the transport sector at the national level. India's Long-Term Low-Carbon Development Strategy (LT-LEDS), submitted under the Paris Agreement in 2022, identifies some broad elements for long-term low-carbon growth in this sector, such as improving fuel efficiency, phased adoption of cleaner fuels, electrification, and enabling a modal shift (MoEFCC 2022). However, it does not provide a low-carbon roadmap with clear time-bound strategies and targets. A series of expert consultations organized by WRI India (WRI India 2020a) revealed similar gaps in decarbonizing transport in India: first, policymakers lack credible scenarios regarding the future GHG emissions that would be generated if current policies continue, and second, there is limited knowledge of the GHG mitigation potential of different transport-related policies corresponding to the different elements identified in the LT-LEDS. A systemic literature review of low-carbon transport studies in the Global South highlighted the lack of studies on sub-sectoral mitigation potential, a gap that this working paper seeks to address (Emodi et al. 2022).

This working paper seeks to address the above-mentioned gaps. We develop a decarbonization roadmap through a scenario-based modeling approach with BAU and ambitious policy scenarios, quantifying the mitigation potential of various strategies in each scenario.

We use the India Energy Policy Simulator (EPS) to provide a scenario-based simulation of transport sector policies with their mitigation potential and their impact on energy usage. This would help policymakers understand the mitigation potential of various policies, identify their energy consumption reduction opportunities, and identify, easy-to-implement strategies. Such efforts will help policymakers prioritize mitigation actions within the transport sector, develop and combine associated emissions reduction strategies, and set emissions reduction targets.

This working paper is organized as follows. The section titled "Study methodology and limitations" details the methodology and limitations of our approach. The section titled "Decarbonization scenarios and policy targets" discusses the BAU scenario trends and highlights the estimated impacts of the three decarbonization strategies (fuel economy standards, electrification, and modal shift). The section titled "Policy implications," based on the findings from the scenarios, discusses a few policy implications followed by next steps. The insights provided in this working paper will serve as useful guiderails for policymakers in exploring various strategies, targets, and pathways to reduce GHG emissions from the transport sector in India.

STUDY METHODOLOGY AND LIMITATIONS

The scenarios presented in the working paper use the India EPS, an open-source, systems-dynamics model developed by Energy Innovation LLC and adapted for India in collaboration with WRI India. The input parameters and the associated assumptions are presented in Swamy et al. (2021a). Please note that the India EPS is not a forecasting tool. Instead, the approach is to create "what-if" scenarios to evaluate the impact of alternative policy levers (Swamy et al. 2021b).

A study of models similar to the EPS highlighted several gaps, including the availability of limited policy levers and the inability to set time-bound targets (Kumar et al. 2022). The EPS was selected due to the availability of a wide range of policy levers that can be included in scenario development, open-source access, and ease of analysis.

The key policies modeled in the transport sector include fuel economy standards, the EV sales mandate, and modal shift (see Decarbonization strategies for details). In the absence of policy levers, for the transport sector, the India EPS selects vehicle technologies that meet the BAU travel demand for a given year by optimizing the capital and operating costs of the vehicles. This means that the travel demand will be met with least-cost technologies unless there is a policy-based assumption, such as an EV sales mandate, which will override the least-cost logic (Swamy et al. 2021a).

The following methodology was followed:

- First, a BAU scenario was developed using the India EPS to understand the impact of existing policies on parameters such as CO_2 emissions and energy consumption. All the assumptions used when developing the baseline scenario were vetted through extensive expert consultations (Swamy et al. 2021a).
- Next, the strategies related to the transport sector were identified from India's LT-LEDS. These strategies were mapped with the policy levers available in the India EPS (see Table 2).
- The identified policy levers corresponding to each strategy were used to create three different scenarios based on varied levels of ambitions: low, medium, and high (see Appendices B–D for assumptions related to the ambition level for each policy lever mapped under each strategy).
- The impact of each strategy, based on modeling the identified policy levers individually and cumulatively, on emissions and energy consumption was modeled through low-, medium-, and high-ambition levels for 2050. The results and key findings along with policy implications are presented in the subsequent sections.

The following are the limitations of our methodology:

- The analysis presented in the working paper is based on scenario development that evaluates the impacts of various policy levers rather than enacting a set of policies that will meet a predetermined result(s).
- Some uncertainties within the India EPS cannot be quantified. For example, data gaps in a few input variables require broader assumptions (e.g., fuel elasticity) and make it impossible to consider certain effects such as the rebound effect of efficiency policies.
- Although the India EPS captures the co-benefits of policies, it does not capture the distributional impacts of those co-benefits across states and population groups.
- This working paper does not examine the social implications of the strategies and policy levers that guide the scenario modeling. Besides, an analysis of economic parameters such as the impact of the strategies and actions on jobs and the GDP is outside the scope of this paper. An assessment of the complexity and feasibility of implementing the policy levers is also outside the scope of the India EPS.
- The scenarios presented in this working paper pertain to the transport sector only, and interactions with other key economic sectors have not been considered.
- The India EPS does not include policy levers on nonmotorized transport, metro, and waterways. In addition, the India EPS also does not represent last-mile connectivity modes.
- The India EPS does not include a disaggregation of vehicle segments by ownership (private or public).

DECARBONIZATION SCENARIOS AND POLICY TARGETS

BAU trends in the transport sector

The estimated future travel demand, energy consumption, and associated emissions under existing policies are shown for 2030, 2040, and 2050 in Table 1. The assumptions for this scenario (BAU) are presented in Appendix A (Swamy et al. 2021a).

Passenger travel demand triples between 2020 and 2050.[1] The passenger travel vehicle segments included in the model are buses, three-wheelers, two-wheelers, passenger

Table 1 | **Estimated future travel demand and CO_2 emissions for the BAU scenario**

	2020	2030	2040	2050
TRAVEL DEMAND				
Passenger demand (trillion passenger-km/year)	8	15.9	21.1	25.7
Freight (trillion freight-km/year)	2.8	6.7	10.45	13.89
FOSSIL FUEL USE				
Fossil fuel use (petajoules/year)	3,976	7,500	9,324	11,027
CO_2 EMISSIONS				
Emissions (million tonnes/year)	293	563	703	832

Note: BAU = business as usual. CO_2 = carbon dioxide.

Source: Generated by the authors using the India Energy Policy Simulator.

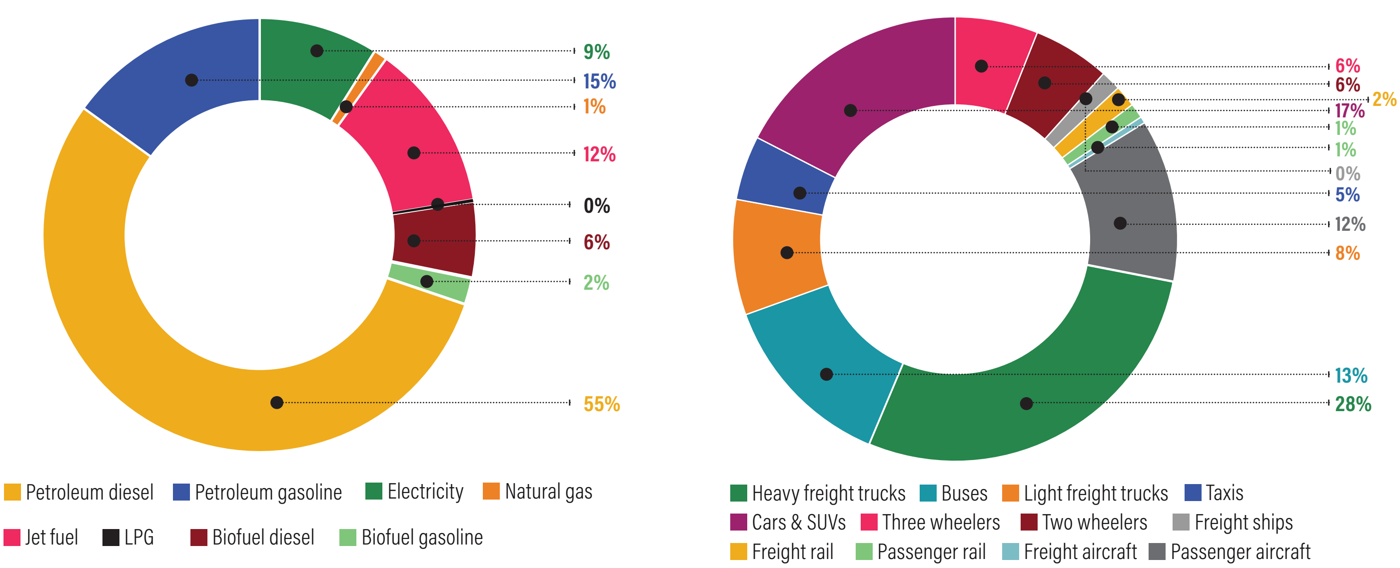
rail, passenger aircraft, taxis, cars, and sports-utility vehicles (SUVs). According to the BAU scenario, nearly 50 percent of the total demand in 2050 (12 trillion passenger-km/year) is likely to come from buses alone, indicating the need to augment public transport fleets, improve infrastructure, and enable equitable access to ensure that this demand is not shifted to private transport modes.

Freight travel demand is likely to increase five times between 2020 and 2050, with freight HDVs accounting for 40 percent of the demand. Freight modes included in the tool are freight LDVs, freight ships, freight HDVs, and freight rail. This highlights the need for new technologies and investments for decarbonizing trucking.

Fuel consumption is likely to be dominated by fossil fuels in 2050. Fossil fuel consumption (petroleum diesel, petroleum gasoline, natural gas, and LPG) is expected to triple over the next three decades. Seventy percent of fossil fuel usage in 2050 is likely to come from diesel and gasoline (Figure 1). In this scenario, freight HDVs account for the largest share of fossil fuel consumption (28 percent), followed by cars and SUVs (17 percent) (Figure 1).

As indicated by the BAU scenario, fossil fuels will continue to dominate the energy mix in transport, and emissions are likely to quadruple by 2050, highlighting the urgency for an aggressive low-carbon strategy targeting the passenger and freight segments.

Figure 1 | **Percentage fuel consumption by fuel type and vehicle type in 2050 in the BAU scenario**



Note: BAU = business as usual. LPG = liquefied petroleum gas. SUV = sports utility vehicle.

Source: WRI India analysis using the India Energy Policy Simulator (all units in petajoules/year).

Decarbonization strategies

India's LT-LEDS for transport includes four main elements (MoEFCC 2022):

- Improving fuel efficiency
- Phased adoption of cleaner fuels
- Modal shift toward public transport and less-polluting modes of transport
- Electrification across multiple modes such as rail and road transport

The various elements of India's LT-LEDS were used as the basis for identifying three main strategies for this analysis: stringent fuel economy standards, electrification, and modal shift to less carbon-intensive modes. A shift toward cleaner fuels was not included in this exercise because there are no relevant policy levers available in the India EPS for this mode. Each strategy is analyzed at its low-, medium-, and high-ambition levels to identify the pathway that maximizes the impact in terms of emissions reduction potential.

Each strategy was built incrementally (from low ambition to high ambition) to capture the decarbonization potential. The values for policy levers at the low- and high-ambition levels were taken from research studies and secondary literature sources such as global best practices, national policy documents, and existing national or global targets. The three strategies were modeled using the India EPS. The policy levers within each chosen strategy are provided in Table 2. Detailed assumptions for all the strategies are included in Appendices B–D.

Table 2 | **Key policy levers included in the strategies**

STRATEGY	POLICY LEVER
Fuel economy	▪ Fuel economy standards (percentage increase in km/liter) for passenger cars, SUVs, buses, freight LDVs and freight HDVs, passenger rail, freight rail, passenger taxi, freight ships, two-wheelers, and three-wheelers
Electrification	▪ Electric vehicle sales mandate for all passenger and freight vehicle types ▪ Hydrogen vehicle sales mandate
Modal shift	▪ Percentage of travel demand shifted from passenger vehicles to public transport ▪ Shift from freight HDVs to rail, including increasing track infrastructure, reducing freight fares, full development of dedicated freight corridors (DFCs), and improving flexibility of rail through provision of the last-mile door-to-door connectivity

Note: HDV = heavy-duty vehicle. LDV = light-duty vehicle. SUV = sports-utility vehicle.
Source: India Energy Policy Simulator.

Strategy 1: Improved fuel economy

This strategy focuses on improving fuel economy standards (percentage increase in km/liter) for new vehicle sales in the passenger and freight segments between 2020 and 2050. It specifies a percentage improvement in fuel economy (due to fuel economy standards for newly sold vehicles of the selected types with fossil-fuel-driven internal combustion engines) over the BAU fuel economy improvements. Fuel economy can be measured as the distance traveled with the same quantity of fuel with the same cargo or passenger loading levels. Three scenarios at varying ambition levels were developed to assess the impact of this strategy. No other strategies were modeled. This scenario does not include the effect of induced demand for passenger vehicles with improved fuel economy. However, it does account for vehicle scrappage and also includes assumptions regarding vehicle lifetimes for all segments, after which they are replaced. Table 3 details the impact of the policy levers on CO_2 emissions at different ambition levels. The values used for the various policy levers at low- and high-ambition levels are provided in Appendix B.

THE EXISTING POLICY LANDSCAPE

- The Corporate Average Fuel Economy (CAFE) norms for passenger cars implemented in 2015 require that average CO_2 emissions be less than 113 g/km. This could be further tightened to 108 or 104 g/km (Anup and Deo 2021).
- Two-wheelers comprised more than 80 percent of total vehicle sales in India in the fiscal year (FY) 2020–21. However, there are currently no fuel efficiency standards for this segment (Anup and Deo 2021), the norms for which are being finalized (BEE 2023).
- Fuel efficiency norms were introduced for heavy-duty commercial vehicles weighing over 12 tonnes in 2017, based on the constant speed fuel consumption test (BEE 2023). Similarly, in 2019, fuel consumption limits were also set for light and medium commercial vehicles with gross vehicle weights between 3.5 and 12 tonnes.

PROPOSED POLICY TARGETS AT THE HIGH-AMBITION LEVEL

- In the BAU scenario, the fuel economy of passenger LDVs improves by 9 percent from 2019 levels by 2022. The fuel economies of passenger HDVs and freight HDVs improve by 19 percent and 17 percent, respectively, from 2019 levels by 2022. The fuel economy of freight ships is projected to improve by 34 percent between 2020 and 2050 (Swamy et al. 2021b).
- At the high-ambition level, India can set a target of improving the fuel economy of cars and SUVs by 60 percent, of buses by 75 percent and light commercial trucks by 60 percent, of freight ships by 30 percent, and of

Table 3 | **Impact of fuel economy standards (low and high ambition) on percentage CO_2 emissions reduction by 2030 and 2050**

VEHICLE CATEGORY	LOW AMBITION			HIGH AMBITION		
	ASSUMPTION	2030	2050	ASSUMPTION	2030	2050
Indicator: Percentage increase in km per liter by vehicle type (%)						
Three-wheelers	23	▼3	▼11	50	▼8	▼21
Two-wheelers	23			50		
Freight ships	15			30		
Freight HDVs	30			60		
Freight LDVs	30			60		
Buses	30			75		
Cars and SUVs	16			60		
Taxis	16			60		

Note: CO_2 = carbon dioxide. HDV = high-duty vehicle. LDV = light-duty vehicle. SUV = sports-utility vehicle.
Source: India Energy Policy Simulator.

three-wheelers and two-wheelers by 50 percent between 2020 and 2050, above the improvements projected in the BAU scenario. The rationale for such assumptions is provided in Appendix B.

IMPACTS

By 2050, the low- and high-ambition levels reduce CO_2 emissions by 11 percent per year and up to 21 percent per year, respectively, compared to BAU emissions.

The majority of the emission reductions comes from taxis, freight LDVs, and buses (27 percent reduction by 2050 compared to BAU values).

By 2050, low- and high-ambition levels result in a reduction in fossil fuel energy consumption of 10 percent per year and up to 19 percent per year, respectively, compared to BAU consumption.

Strategy 2: Electrification

This strategy focuses on fleet electrification, driven by EV and hydrogen vehicle (H2V) sales mandates for all vehicle segments. Manufacturers may meet a sales standard through techniques such as intensive marketing of EVs, lowering the purchase cost of EVs, or raising the price of nonefficient vehicles by implementing a fee that is rebated to buyers of efficient vehicles. Many buses are purchased by government agencies for transit, so this policy can be used to represent government procurement policies that favor electric buses. Three scenarios of varying ambition levels were developed to assess the impact of this strategy. No other strategies were modeled. This scenario assumes that the share of renewable energy (RE) in electricity generation (primarily solar and wind; biomass remains negligible) is 10 percent in the start year, increasing to 27 percent through 2030 and 55 percent through 2050, as modeled in the BAU scenario. Table 4 details the impact of the policy levers on CO_2 emissions at different ambition levels. The values for the policy levers at low- and high-ambition levels are given in Appendix C. This strategy also includes the impact of supplementary policy levers such as charger deployment, EV subsidies, feebates, and reduction in range concern, which are detailed in Appendix C.

EXISTING POLICY LANDSCAPE

- India has an overall target of achieving an EV sales penetration of 30 percent for private cars, 70 percent for commercial cars (taxis), 40 percent for buses, and 80 percent for two-wheelers and three-wheelers by 2030 (PIB 2019a).
- The cabinet introduced the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME II) scheme in 2019, which provides incentives for public transport and commercial three- and four-wheelers. It also proposes setting up one charging station per 3 km × 3 km grid (PIB 2019b).
- A total of 7,210 buses and 9,441 charging stations have been sanctioned under this scheme so far (MHI n.d.). The state-owned Convergence Energy Services Limited (CESL) announced one of the largest e-bus procurement

tenders, aiming to deploy 5,450 e-buses across five major cities in India under FAME II (Dawra et al. 2022). The PM E-bus Sewa Scheme was also launched in 2023 with the aim of deploying 10,000 electric buses on a public-private partnership basis (PIB 2023b).

- In January 2023, India also announced the National Green Hydrogen Mission with an outlay of INR 19,744 crore (INR 197,440 million), with a focus on developing green hydrogen hubs, developing skills, and implementing pilots for the use of green hydrogen in various segments such as mobility and shipping (PIB 2023c). The demand for hydrogen is expected to grow by 2050, particularly in the heavy freight and shipping segments. However, the competitiveness of H2Vs relative to EVs depends on reductions in capital costs and the availability of refueling infrastructure. By 2050, nearly 80 percent of India's hydrogen is projected to be green, produced through RE-driven electrolysis (Hall et al. 2020).

PROPOSED POLICY TARGETS AT THE HIGH-AMBITION LEVEL

- This strategy includes electrification targets for different categories of vehicles, such as freight, which has not been included in current policies.
- At the high-ambition level, H2V sales mandate targets, which are considered for buses, freight HDVs, passenger and freight rail, and freight ships, are assumed to take effect from 2030 onward, assuming technology development. The Indian government is also piloting hydrogen railways, another segment that is likely to see green hydrogen proliferation (PIB 2023c). Hydrogen railways have several advantages over electric railways. Unlike electric trains, they do not need overhead wires, and they also require less infrastructure to set up, especially for retrofitting existing lines. They need only hydrogen refueling stations, and hydrogen fuel cells can provide longer ranges than batteries, which is especially important in areas with limited refueling infrastructure. They also refuel quickly, similar to diesel trains (Konieczny et al. 2023).
- H2V sales mandates were not used for other segments, because it is anticipated that BEVs will continue to be more cost-effective than H2Vs for short-distance segments (Hall et al. 2020).

IMPACTS

- By 2050, the low- and high-ambition levels result in a reduction of CO_2 emissions of 17 percent per year and up to 57 percent per year, respectively, compared to BAU emissions.
- The majority of the emissions reduction comes from buses (80 percent), three-wheelers (78 percent), and two-wheelers (74 percent). By 2050, the low- and high-ambition levels reduce fossil fuel energy consumption by 15 percent per year and up to 56 percent per year, respectively.

Table 4 | **Impact of electrification (low and high ambition) on percentage CO_2 emissions reduction by 2030 and 2050**

VEHICLE CATEGORY	LOW AMBITION			HIGH AMBITION		
	ASSUMPTION	2030	2050	ASSUMPTION	2030	2050
Indicator: Percentage of new vehicles sold (by vehicle type) (%)						
Electric vehicles sales mandate						
Three-wheelers	80	▼1	▼17	100	▼4	▼57
Two-wheelers	80			100		
Freight rail	100			85		
Passenger rail	100			85		
Freight HDVs	30			60		
Freight LDVs	30			70		
Buses	50			95		
Cars and SUVs	30			100		
Taxi	70			100		

Table 4 | **Impact of electrification (low and high ambition) on percentage CO_2 emissions reduction by 2030 and 2050 Cont..**

Hydrogen vehicle sales mandate						
Freight rail	0			25		
Passenger rail	0			25		
Freight HDVs	0			25		
Buses	0			5		
Freight ships	0			25		

Note: CO_2 = carbon dioxide. HDV = high-duty vehicle. LDV = light-duty vehicle. SUV = sports-utility vehicle.
Source: Authors' analysis using the India Energy Policy Simulator.

Strategy 3: Modal shift toward low-carbon modes

This strategy looks at the modal shift of transport demand toward low-carbon modes. It includes policy levers for the shift of passenger demand from private to public transport and freight demand from freight HDVs to rail freight. Three scenarios were developed at varying ambition levels to assess the impact of this strategy. No other strategies were modeled. The values for the policy levers at low- and high-ambition levels are given in Appendix D. Table 5 details the impact of the policy levers on CO_2 emissions at different ambition levels.

EXISTING POLICY LANDSCAPE

- Passenger and freight modes rely heavily on road transportation, which is dominated by fossil fuel. In 2019, for road passenger transport, the fleet share of private vehicles was 88 percent whereas that of buses was less than 1 percent (MoRTH 2021).
- Seventy percent of freight is road based, whereas 30 percent is rail and water driven in India (Sinha et al. 2021).
- Although there are no overarching targets or policy for modal shift, several cities have included modal shift targets for public transport in their comprehensive mobility plans.
- The National Rail Plan aims to increase the share of rail freight to 45 percent by 2030, mainly by constructing dedicated freight corridors (PIB 2022a).

PROPOSED POLICY TARGETS AT THE HIGH-AMBITION LEVEL

At the high-ambition level, it is proposed that 35 percent of travel demand from freight HDVs shifts to rail freight, and 35 percent of demand from taxis and from passenger cars each shifts to public transport.

This scenario assumes the implementation of demand measures for shifting demand from private transport, such as parking charges, increased registration taxes, and improvement in public transport quality, reliability, integration, and affordability (Dhar et al. 2015). A study in Bonn highlighted that expanding transport services reduced wait times and increasing the number of bus stops resulted in a positive modal shift from private vehicles to public transport (Hahn et al. 2023).

The shift from road freight to rail freight assumes the implementation of measures to improve track utilization, freight fare rationalization, development of the Dedicated Freight Corridors (DFC) project, increase in the commodities moved by rail, and improved end-to-end logistics for customers. According to the Council on Energy, Environment and Water's (CEEW's) study on India's transport outlook, 21 percent of passenger demand is expected to be served by two-wheelers, 45 percent by four-wheelers, and 3 percent by three-wheelers in 2050 (Kamboj et al. 2022).

IMPACTS

- By 2050, the low- and high-ambition levels result in a CO_2 emissions reduction of 5 percent per year and up to 18 percent per year, respectively, compared to BAU emissions.
- The majority of the emissions reduction comes from taxis, cars, and HDVs (35 percent).
- By 2050, the low- and high-ambition levels can enable a reduction in fossil fuel energy consumption of 6 percent per year and 18 percent per year, respectively, compared to the BAU consumption.

Table 5 | **Impact of modal shift (low and high ambition) on percentage CO_2 emissions reduction in 2030 and 2050**

INDICATOR	LOW AMBITION			HIGH AMBITION		
	ASSUMPTION	2030	2050	ASSUMPTION	2030	2050
Percentage shift of travel demand from freight HDVs to rail freight	10	▼2	▼5	35	▼6	▼18
Percentage reduction in air trips	5			10		
Percentage shift of passenger travel demand from private to public vehicles	10			35		

Note: CO_2 = carbon dioxide. HDV = heavy-duty vehicle.

Source: Authors' analysis using the India Energy Policy Simulator.

Cumulative impacts of strategies on energy and emissions from the transport sector

Various scenarios were developed to quantify the cumulative impact of the three strategies (fuel economy, electrification, and modal shift) in different combinations. This provided insights into strategies for maximizing emissions reductions. This can provide a basis for policymakers to understand the mitigation potential of various levers and work toward developing decarbonization targets and a roadmap for the transport sector. (Refer Table 6 for details)

Table 6 | **Cumulative impacts of all possible combinations of the three strategies**

STRATEGY 1 (FUEL ECONOMY STANDARDS)	STRATEGY 2 (ELECTRIFICATION)	STRATEGY 3 (MODAL SHIFT TOWARD LOW-CARBON MODES)	TRANSPORT CO_2 EMISSIONS REDUCTION COMPARED TO BAU BY 2050 (%)	TRANSPORT FOSSIL FUEL ENERGY REDUCTION COMPARED TO BAU BY 2050 (%)
30–40% emissions reduction by 2050				
Low	Low	Low	32	30
Low	Low	Medium	37	35
Medium	Low	Low	37	36
40–60% emissions reduction by 2050				
Low	Low	High	41	40
Medium	Low	Medium	41	40
High	Low	Low	42	40
Low	Medium	Low	43	42
High	Low	Medium	45	44
Medium	Low	High	46	45
Low	Medium	Medium	47	46
Medium	Medium	Low	47	46
High	Medium	Low	49	47
High	Low	High	50	49

Table 6 | **Cumulative impacts of all possible combinations of the three strategies Cont...**

Low	Medium	High	51	50
Medium	Medium	Medium	51	50
High	Medium	Medium	52	51
Medium	Medium	High	55	54
High	Medium	High	56	55
60–71% emissions reduction by 2050				
Low	High	Low	64	63
Low	High	Medium	66	65
Medium	High	Low	66	65
Medium	High	Medium	67	67
Low	High	High	68	67
High	High	Low	68	67
High	High	Medium	69	68
Medium	High	High	70	69
High	High	High	71	71

Note: BAU = business as usual. CO_2 = carbon dioxide.

Source: Authors' analysis using the India Energy Policy Simulator.

KEY OBSERVATIONS

- Implementing the electrification strategy at a high-ambition level alone can result in a 57 percent emissions reduction by 2050 compared to BAU values. Implementing it with the other two strategies at the low-, medium-, or high-ambition level has the highest emissions and energy consumption reduction potential (60–71 percent). This indicates the need to continue efforts toward electrifying passenger fleets and introducing sales mandates for electric freight and H2Vs in the long term.
- Implementing all three strategies at a low-ambition level results in a 32 percent reduction in CO_2 emissions and a 30 percent reduction in fossil fuel energy consumption by 2050. Increasing either the modal shift or fuel economy standards to a high-ambition level while keeping the other two strategies at a low-ambition level can result in a 41–42 percent reduction in CO_2 emissions. However, increasing the electrification strategy to a high-ambition level while keeping the other two strategies at a low-ambition level can increase the CO_2 emissions reduction potential to 64 percent by 2050.

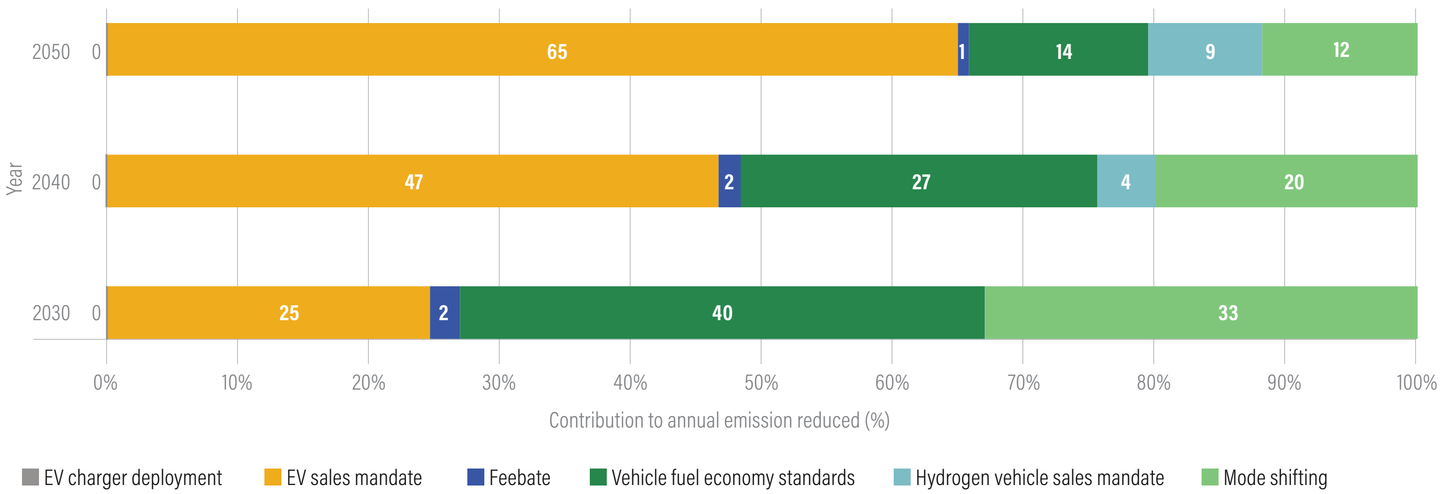
As mentioned above, emissions reduction from the transport sector will be pivotal to achieving India's net-zero target by 2070. This can be achieved by implementing all three strategies (stringent fuel economy standards, electrification, and modal shift toward public transport and low-carbon freight modes) at a high-ambition level, resulting in a 71 percent reduction in both CO_2 emissions and fossil fuel energy consumption compared to BAU values by 2050.

The likely outcomes of various policy levers in terms of sectoral emissions reduction are shown in Figure 2. Policymakers in India can use this figure to explore the different policy levers and their impact on transport sector decarbonization, set potential sector-wide emissions reduction targets, and develop a roadmap.

ANALYSIS

- Stringent fuel economy standards for all segments play a key role, and the gains are more immediate (contributing to a 40 percent reduction in total CO_2 emissions in 2030 compared to BAU values). Currently, there are no fuel economy standards for two-wheelers and three-wheelers. Methods such as green vehicle rating, which quantifies the environmental impacts of a vehicle model, can be used to develop CAFE standards for two- and three-wheelers, similar to those for cars (Kumar et al. 2018). Engine and tire improvements can enable the highest fuel economy improvements and return on investment for trucks (Sinha et al. 2021). There is also a pressing requirement to overhaul the current implementation of the

Figure 2 | **Contribution of policy levers to CO_2 emissions reductions with all three strategies at high ambition (million tonnes/year)**



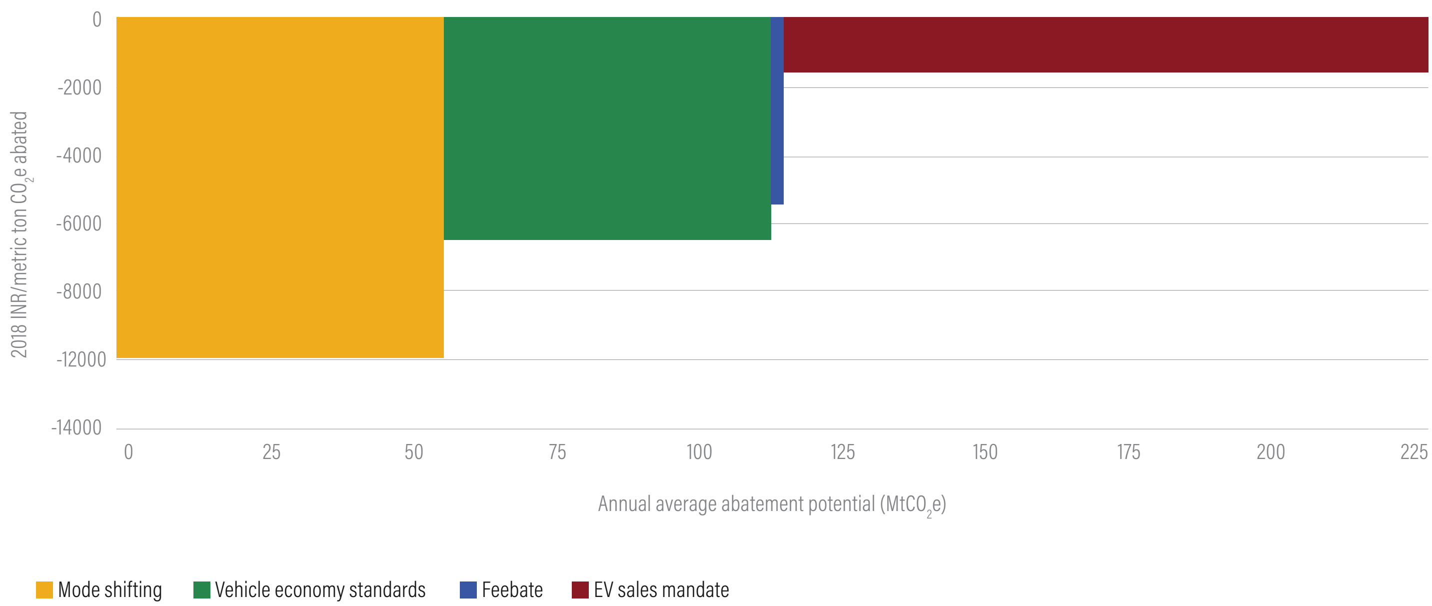
Note: CO_2 = carbon dioxide. EV = electric vehicle.

Source: Authors' analysis using the India Energy Policy Simulator.

Pollution Under Control (PUC) program, which remains riddled with malpractices and poor data records (Raman and Shukla 2018).

- Modal shifts from private vehicles to public transport and from road freight to rail by 2050 will contribute to significant CO_2 emissions reduction in the near and medium term. A three-city survey conducted by WRI India in 2023 found that lack of publicity regarding available last-mile feeder services, low frequency and high waiting times, and high fare structures were some factors that disincentivized the shift toward the metro (Mukherjee et al. 2023). The study also found that women, who tend to make shorter trips, are disincentivized by the fare structures for shared public transport. Soft interventions to enable a behavioral shift toward public transport, such as awareness campaigns; ticketing and informational smartphone applications (apps); increased comfort at stations and in the bus/metro; and monetary incentives can also play an important role (Zarabi et al. 2021). This can also be coupled with demand management measures such as parking charges.
- Shifting road freight demand toward railways would require continuous investments aimed at improving and utilizing infrastructure and improving intermodal integration, which would require integration between shipping, truck operators, and Indian Railways. Currently, over two-thirds of India's railway lines are overutilized. Moreover, because passenger and freight rail share the same tracks, passenger rail is prioritized, reducing the speed and transit time of rail freight. Freight trains run at an average speed of 40 kmph in India (PIB 2022b). Increasing rail infrastructure would also require new freight corridors with high-capacity rail networks. There is also scope for transitioning a portion of bulk goods from road to rail (Sinha et al. 2021).
- An EV sales mandate makes the largest contribution to sectoral emissions reduction in 2050 (65 percent), followed by vehicle fuel economy (14 percent), modal shift (12 percent), and a hydrogen sales mandate (9 percent). There is a need to introduce electrification targets for the freight segment, perhaps in the next phase of the FAME scheme.
- The impact of hydrogen fuel sales mandates is likely to be seen from 2040 onward provided India implements effective policies and the necessary infrastructure. Green hydrogen has the potential to reduce carbon emissions in hard-to-abate transport segments such as HDVs, shipping (smaller ferries), rail, and aviation. Some challenges that need to be overcome include high initial infrastructure costs, safety concerns regarding storage and transport, and the need for specialized storage tanks (Maitra et al. 2023).
- Modal shift provides the highest net savings, and the EV sales mandate provides the highest CO_2e emissions reduction. Figure 3 shows the CO_2e abatement cost curve for policies at a high-ambition level through 2050. The least-cost policy with the highest net savings is a modal shift toward public transport for road passenger demand and toward railways for road freight, providing significant annual CO_2e abatement with approximate savings of INR 12,118 per tCO_2e abated.[4] However, the India EPS does not account for the associated infrastructure costs of supporting this modal shift.[5]
- The EV sales mandate is the most effective in reducing CO_2e emissions, with an annual abatement potential of 121 $MtCO_2e$.

Figure 3 | **CO_2e abatement cost curve for transport sector policies in the scenario with all three strategies implemented at high ambition**



Note: Estimates are provided according to the 2018 rate of the Indian rupee: 69.1 INR = 1 US$. CO_2e = carbon dioxide equivalent. EV = electric vehicle.

Source: Authors' analysis using the India Energy Policy Simulator.

Potential for additional emissions reduction using Strategy 4: Optimizing capacities

Optimizing existing transport capacities could serve as a fourth strategy for reducing emissions and decarbonizing the sector. However, this has not been modeled using the India EPS. A review of 56 state road transport undertakings between 2017 and 2019 highlighted a 60–70 percent bus occupancy ratio (MoRTH 2023). This strategy builds on the notion that an empty seat in a vehicle or empty truck is a wasted resource, and this wastage has to be minimized.

PROPOSED OPTIMIZATIONS

This strategy assumes innovative ways of servicing passenger and freight demand that will lead to the demand being met by lower vehicle-km and tonne-km, respectively, which will directly impact per capita energy consumption.

- Policies and regulations incentivizing shared mobility, mobility as a service (MAAS), ride sharing, and carpooling are some of the measures for passenger transport that can help maximize occupancies, thus reducing emissions and fuel use.
- For freight transport, different options may be explored to increase the gross volume weight rating, thereby decreasing the total tonne-km traveled.

IMPACT

Shared mobility can be defined as any transportation shared by users on an as-needed basis (Bhandari et al. 2018), such as ride sharing or bike sharing with two-wheelers, three-wheelers, and four-wheelers. With shared mobility, India can further reduce cumulative emissions by 1 gigatonne (Gt) of CO_2 by 2030 **(i.e., by focusing on shared mobility, an additional 17 percent emissions reduction is possible by 2030 in addition to that obtained with the existing policy levers) (Bhandari et al. 2018).**

Further, in freight transport, optimized truck use has a cumulative mitigation potential of 2.7 GtCO_2 between 2020 and 2050 (i.e., a 30-year time frame). Trucks in India run an average of 300 km per day, which is much lower than the global average of 500–800 km per day, with high empty-running rates of 40 percent. Improving packaging efficiency, reducing intermediary agents, digitizing the process of matching fleet operators to shippers, and using bigger trucks with higher carrying capacities can help optimize trucking efficiencies (Sinha et al. 2021).

POLICY IMPLICATIONS

- **Fleet electrification efforts need to be accompanied by grid decarbonization to achieve greater overall mitigation.** However, although electrification provides emissions reduction benefits in the long run, when considered together with upstream emissions from the power sector, the impacts may not be substantial. Hence, ambitious electrification targets in the transport sector need to be accompanied by grid decarbonization. For example, the scenario with all three strategies implemented at a high-ambition level results in a total transport sector emissions reduction of 71 percent compared to BAU values. If an additional policy lever—namely, a carbon-free electricity standard—is implemented, with 75 percent of electricity generation coming from RE by 2050, the result is a 75 percent reduction in overall transport sector emissions by 2050 compared to BAU values.
- **A modal shift toward buses can significantly reduce road passenger demand.** It was observed that the future growth of passenger demand will be driven by economic development (Kamboj et al. 2022). However, implementing a modal shift toward public transport for passenger modes at a high-ambition level can reduce passenger demand for taxis, cars, and SUVs by 35 percent each, by 2050. This shift should be accompanied by increased last-mile connectivity to mass transit hubs, railway stations, and bus stops. There is a need to develop guidelines for physical infrastructure integration, fare integration, information technology, and interoperability for buses with other modes (metro, suburban rail, airports, railway stations, major activity centers, service areas, etc.) to ensure better public transport uptake (WRI India 2020b).
- **Fuel economy standards need to be implemented alongside complementary emissions taxes.** Fuel economy standards specify a percentage improvement in fuel economy for newly sold fossil-fuel-based vehicles. Fuel economy standards improve the efficiency of new vehicles, but in the absence of complementary emissions tax policies, some of this gain may be offset by increased vehicle use due to the cheaper cost per kilometer of traveling. This "rebound effect" is exacerbated if fuel is subsidized rather than taxed. Hence, emissions taxes on fossil fuels are thus a useful complement to fuel economy standards to maximize emissions reductions (Zheng et al. 2022).
- **India's 2030 EV sales mandates need complementary interventions such as adequate charging infrastructure, reduction in range anxiety, and additional incentives (e.g., feebates and subsidies) to maximize decarbonization.** Our scenarios show that a high-ambition level with a 100 percent reduction in range anxiety, 250 chargers per 100,000 population, EV subsidies, and a feebate equaling 50 percent of global best practice can result in a 57 percent emissions reduction compared to BAU values by 2050. To achieve its 2030 EV sales mandate targets, India would require 1.3 million EV charging stations by 2030 (i.e., 250 chargers per 100,000 population), integrated within town planning (CII 2023) and grid planning (Singh et al. 2021). A limitation of the EPS is that it sets a cap of 250 chargers per 100,000 population. However, more charging infrastructure would be required by 2050. New technologies should aim for a 100 percent reduction in range anxiety. Range anxiety remains high for three-wheelers because they are used for commercial purposes. Hence, any downtime can reduce the revenue of the operator. Range anxiety also remains high for passenger vehicles and buses, especially those used for intercity travel (Mulugund et al. 2022).

NEXT STEPS

This working paper analyzes the decarbonization potential of three strategies for the transport sector and examines their impacts at different levels of ambition (low, medium, and high). Such scenario analysis is just the first step. A more detailed sectoral analysis is required to understand the socioeconomic impacts of such a transition. In addition, this analysis can spur a discussion among policymakers on the subject of also considering specific decarbonization targets for the transport sector while developing India's next round of ambitious climate commitments under the Paris Agreement. The implementation of various policies within each strategy highlighted here would require stakeholder dialogues to determine the feasibility of such interventions in terms of technical and socioeconomic constraints, implementation challenges, and financial needs. Policymakers will also need to devise implementation plans to enable deep decarbonization of the transport sector in India.

For example, an aggressive transport electrification strategy also entails recycling and scrappage solutions. The demand for batteries will increase significantly in view of India's commitment to transitioning fossil-fuel-based vehicles to EVs. These batteries have a shelf life of eight to ten years. When the energy storage capacity of these batteries drops to ~80 percent, they become unfit for EVs (Singh and Verma 2021). The need to recycle EV batteries stems from the need to mitigate supply issues, optimize second-life applications, and reduce emissions and the environmental impact (Bhattacharjee 2023). The Government of India recently notified the Battery Waste Management Rules, 2022 (PIB 2022c). The battery recycling sector, however, needs to scale up rapidly in areas such as robust reverse logistics, efficient and cost-effective recycling techniques, recovery of battery-grade materials from black mass, and development of active domestic material manufacturing industries. Therefore, stakeholders such as authorities, automakers, battery manufacturers, and recycling establishments must collaborate to accelerate development of the ecosystem.

The analysis presented in this paper assumes 100 percent electrification of railways by 2030 in the electrification strategy across all ambition levels. A small proportion of hydrogen-powered railways is also considered by 2050 due to India's proposed plan for hydrogen rail pilots, especially in heritage routes (PIB 2023d). In addition, to phase out diesel locomotives and devise disposal solutions, a scrappage solution has to be developed for existing diesel locomotives, which remains a high-priority issue for Indian Railways (WRI India 2020c). Higher recycling rates and technology upgrades are necessary to support Indian Railway's electrification plans (Rungskunroch et al. 2019).

APPENDIX A. BAU SCENARIO ASSUMPTIONS

Table A-1 | **Business as usual (BAU) scenario assumptions**

POLICY LEVER	DETAILS	VALUE IN BAU CASE RATIONALE
FUEL ECONOMY STANDARDS		
Passenger low-duty vehicles (LDVs)	India adopted Corporate Average Fuel Efficiency (CAFE), which requires a 10% improvement in fuel economy between 2017 and 2021, as well as a 30% improvement starting in 2022.	Fuel economy improves by 9% by 2022 compared to the 2019 level.[a]
Freight LDVs	India has recently notified testing standards of 14 and 5 km/liter for gross vehicle weights (GVWs) of 2.5 and 12 tonnes, respectively.	The fuel economy of freight LDVs is not projected to change. The value assigned is 20 km/liter between 2020 and 2050.
Passenger heavy-duty vehicles (HDVs)	The new fuel consumption standards for HDVs in India include two phases of regulatory compliance, with Phase I going into effect in 2018 and Phase 2 in 2021. Because the regulation applies only to trucks and buses greater than 12 tonnes GVW, these standards do not apply to a significant percentage of the HDV market in India.	The fuel economy for the new passenger HDVs improves by 19% by 2022 compared to the 2019 level.[b]
Freight HDVs	The new fuel consumption standards for HDVs in India include two phases of regulatory compliance, with Phase I going into effect in 2018 and Phase 2 effective in 2021. Because the regulation applies only to trucks and buses greater than 12 tonnes GVW, a significant percentage of the HDV market in India is not subject to these standards.	The fuel economy for the new freight HDVs improves by 17% by 2022 compared to the 2019 level.[c]
Passenger and freight rail	India does not have fuel economy standards for trains.	The fuel economy of new passenger trains is not projected to change between 2019 and 2050.
Passenger and freight ships	India currently does not have fuel economy standards for ships.	The fuel economy of new passenger ships is not projected to change between 2020 and 2050; however, it improves by 34% for freight ships between 2020 and 2050.[d]
Two-wheelers, three-wheelers	India currently does not have fuel economy standards for two- and three-wheelers.	The fuel economy of two- and three-wheelers is not projected to change between 2020 and 2050.
Electric vehicle (EV) charger deployment (chargers per 100,000 population)	0.2.	Under India's Faster Adoption and Manufacturing of Electric Vehicles (FAME II) three-year scheme (2019–22), 2,636 EV charging stations have been sanctioned to be installed (PIB 2020). This translates to 0.2 per 100,000 population in 2022. Because this is negligible, the full range of values for this lever is considered additional to the BAU value.
EV range and charging time	No improvement.	n/a
EV SALES MANDATES		
Passenger cars	34% of the new passenger LDVs are electric by 2050.	Although there is currently no minimum required EV sales percentage in India for any vehicle type, the Ministry of Power has set a target of achieving 30% share of EVs on the roads by 2030 under the National Electric Mobility Mission Plan.[e]
Freight LDVs	13% of new freight LDVs are electric by 2050.	
Passenger HDVs	23% of new passenger HDVs are electric by 2050.	
Freight HDVs	4% of new freight HDVs are electric by 2050.	
Two-wheeled vehicles	38% of new two-wheelers are electric by 2050.	
Taxis	58% of new taxis are electric by 2050.	
Three-wheeled vehicles	30% of new three-wheelers are electric by 2050.	

Passenger rail and freight rail	100% of the new passenger and freight rail fleet is electric by 2036.	India's Ministry of Railways has recently set a target of achieving 100% electrification of the railways by 2024.[f]
EV subsidy: Passenger LDVs, freight LDVs, three-wheeled vehicles	The cap on incentives is 20% of the maximum ex-factory price.	In India, demand incentives are available to EV buyers in the form of a reduced purchase price, under the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME-India) scheme. Phase II of the scheme, scheduled from 2019 to 2024, covers all on-road vehicles.[h]
EV subsidy: Two-wheelers	15% cap according to the new rule effective from June 2023.[g]	
EV subsidy: Passenger HDVs	The cap on incentives for passenger HDVs (classified as e-buses) under FAME II is 40% of the maximum ex-factory price.	
Feebates	Nil.	The feebate is set as a fraction of the global best practice feebate rate, resulting in a fee of approximately INR 75,000 for a vehicle consuming 12 liters per 100 km, assuming the pivot point is 10 liters per 100 km. India currently does not have any feebates.
Hydrogen sales targets	Nil.	India does not have any hydrogen vehicle fleet or sales mandates at present. Indian Oil Corporation Ltd. has initiated a pilot project for use of hydrogen-enriched compressed natural gas (H-CNG) in vehicles as a transition fuel to hydrogen, and NITI Aayog has recommended that H-CNG be notified as an automotive fuel.[i]
Modal shift	The BAU scenario does not envisage any shift in the travel demand for vehicle types.	India Energy Policy Simulator
Percentage of renewable energy (RE) electricity generation	This scenario assumes that the share of RE in electricity generation (primarily solar and wind; biomass remains negligible) is 10% in the start year, increasing to 27% through 2030 and to 55% through 2050, as modeled in the BAU.	India Energy Policy Simulator

Note: n/a = not applicable.

Source: a. Façanha et al. 2012, b. Façanha et al. 2012, Iyer 2012, U.S. EIA 2014, Ministry of Railways 2017, c. Façanha et al. 2012; Iyer 2012; U.S. EIA 2014; Ministry of Railways 2017. *d. Façanha et al. 2012; Iyer 2012; U.S. EIA 2014; Ministry of Railways 2017, e. BEE 2022., f. PIB 2022d., g. Mint 2023., h. PIB 2022e., i. Hall et al. 2020.*

APPENDIX B. ASSUMPTIONS FOR STRATEGY 1 (FUEL ECONOMY STANDARDS)

Table B-1 | **Assumptions for Strategy 1 (fuel economy standards)**

VEHICLE CATEGORY FUEL ECONOMY STANDARDS	IMPROVEMENT IN BUSINESS AS USUAL (BAU)	TARGETS FOR 2050		RATIONALE FOR IMPROVEMENTS OVER BAU VALUES
		HIGH AMBITION	LOW AMBITION	
Passenger light-duty vehicles (LDVs) (cars and taxis)	9% (2019–22)	60%	16%	Considering that India's FY2022–23 standards are much less stringent than those of the European Union's (EU's) 2021 standards, there is considerable scope for Indian regulators to strengthen fleet fuel consumption standards. Currently, the Corporate Average Fuel Efficiency (CAFE) standards specify a limit of 113 gCO2/km from 2022 onward. Based on gasoline equivalent fuel[a] consumption, this translates to a fuel economy of 21 km/liter. Currently, the EU specifies a target of 95 gCO_2/km, which is equivalent to 25 km/liter, a 16% improvement. India can aim for a 16% improvement in fuel economy by 2050 at the low-ambition level. The EU aims for a fuel economy of 50 km/fuel by 2035, a 60% improvement from current levels. This can be used as the basis for the high-ambition level above BAU values.[b]
Passenger HDVs (buses)	19% (2019–22)	75%	30%	The new fuel consumption standards for HDVs in India include two phases of regulatory compliance, with Phase 1 going into effect in 2018 and Phase 2 in 2021. In 2018, the standard for buses (12 tonnes and above at a speed of 60 km/h) was 4.6 km/liter. This was increased to 5.4 km/liter in 2021. The difference between the two phases saw an approximately 5% improvement in fuel economy each year. By improving CO_2 emissions from HDVs, the EU aims to improve fuel economy by 30% by 2030 and by 65% by 2035. Keeping in mind India's current targets, a target of 30% is assumed by 2050 for the low-ambition level and a 75% target is assumed by 2050 for the high-ambition level.[c]
Freight LDVs (light freight trucks)	No change @ 20 km/liter	60%	30%	India has recently notified testing standards for light and medium commercial freight vehicles with a gross vehicle weight (GVW) of 3.5–12 tonnes. To be implemented from April 2020, the fuel economy testing standards are 14 km/liter and 5 km/liter for GVWs of 3.5 and 12 tonnes, respectively (BEE 2023). The EU is aiming for a 30% reduction in CO_2 emission targets and a subsequent improvement in fuel economy for LDVs between 2020 and 2030. This value is assumed for the low-ambition level by 2050 and is doubled for the high-ambition level.[d]
Freight HDVs (medium and heavy freight trucks)	17% (2019–22)	60%	30%	The low-ambition value is taken from the long-term decarbonization scenario in the EPS. This is doubled for the high-ambition level.[e]
Passenger rail freight rail	No change	0%	0%	No fuel economy improvements are assumed for rail because Indian Railways is currently aiming for 100% electrification.
Freight ships	No change	30%	15%	India currently does not have fuel economy standards for ships. The high-ambition value is in line with the long-term decarbonization scenario developed using the EPS (Swamy et al. 2021b). The low-ambition level assumes half the value (15%).
Two- and three-wheelers	No change	50%	23%	Currently, India does not have fuel economy standards for two- and three-wheelers. In the current BAU case, the fuel economy of new two-wheelers is not projected to change between 2019 and 2050. The fleet average of the internal combustion engine two-wheeler is based on the fuel consumption level of FY2018–19, 41.2 gCO_2/km. Anup and Deo (2021) highlighted that a 23% improvement in fuel efficiency by 2030 was feasible without electrification, and this value is doubled for 2050. Similar values are assumed for three-wheelers for the high-ambition level. An improvement of 23% is assumed for the low-ambition level by 2050.

Note: n/a = not applicable.

Source: a. Fuel types include gasoline, diesel, liquid petroleum gas, compressed natural gas, and electricity. Gasoline equivalent fuel consumption (liters/100 km) = 0.04217 (g/liter) × CO_2 emissions (g/km) (Deo and Yang 2021), b. European Commission 2023, c. ICCT 2017, d. Narla et al. 2021, e. Swamy et al. 2021b.

APPENDIX C. ASSUMPTIONS FOR STRATEGY 2 (ELECTRIFICATION)

Table C-1 | **Assumptions for Strategy 2 (electrification)**

POLICY LEVER	BUSINESS AS USUAL (BAU) VALUE	TARGETS FOR 2050		JUSTIFICATION
		HIGH AMBITION	LOW AMBITION	
Electric vehicle (EV) charger deployment (chargers per 100,000 population)	0.2	250	60	3.9 million chargers are needed to meet India's EV sales mandates by 2030, amounting to 250 chargers per 100,000 population. Considering there are just 0.6 chargers per 100,000 population as of 2023, this target is taken for 2050 for the high-ambition level.[a] For the low-ambition level, a value of 60 chargers per 100,000 population is assumed in accordance with the long-term decarbonization scenario.[b]
EV range and charging time	No improvement	100% (no concern)	50%	This policy affects only passenger light-duty vehicles (LDVs). A comprehensive charging infrastructure and improved energy efficiency can eliminate range anxiety.[c] A 100% setting in the India Energy Policy Simulator (EPS) implies that consumers are not more concerned about EV range and charging time than they are about the range and fueling time of gasoline vehicles. Half of this is assumed in the low-ambition level, given rapid improvements in EV models.
EV sales mandate for passenger cars	34% of new passenger LDVs are electric by 2050.	100%	30%	In the high ambition scenario, 100% of new vehicles are assumed to be electric, in line with the International Council on Clean Transportation's (ICCT's) high-ambition level.[d] For the low-ambition level, the 2030 values are assumed as such for 2050.
EV sales mandate for freight LDVs	14% of new freight LDVs are electric by 2050.	70%	30%	The fast electrification scenario in a study by the Centre for Study of Science, Technology, and Policy assumes a 30% fleet electrification of freight LDVs by 2030. This value is retained for 2050 for the low-ambition level.[e] The high-ambition level is in line with the ICCT's projections.[f]
EV sales mandate for passenger HDVs	23% of new passenger HDVs are electric by 2050.	95%	50%	The long-term decarbonization scenario's assumption of 50% (Swamy et al. 2021b) can be taken for the low-ambition level. For high ambition, 95% is assumed, in line with the ICCT's high-ambition level, considering consistent policy support for bus electrification.[g]
EV sales mandate for freight HDVs	4% of the new freight HDVs are electric by 2050	60%	30%	The low-ambition level assumes the value taken for the long-term decarbonization scenario.[h] For a net-zero target, Chaturvedi and Malyani modeled that the share of electric trucks must reach 79% by 2070.[i] Thus, a 60% target is set for 2050.
EV sales mandate for passenger rail and freight rail	100% of the new passenger and freight rail fleet is electric by 2036	85%	100%	100% of the new passenger rail fleet is electric by 2050 in both scenarios based on India's Ministry of Railways target of achieving 100% electrification of the railways by 2024.[j] However, 85% is taken for the high-ambition level to account for a small percentage of hydrogen vehicles.
EV sales mandate for two-wheelers	38% of new two-wheelers are electric by 2050	100%	80%	India is aiming for 80% electrification of two- and three-wheelers by 2030. This is assumed for the low-ambition level until 2050. For the high-ambition level, 100% electrification of the fleet is assumed.[k]
EV sales mandate for three-wheelers	30% of new three-wheelers are electric by 2050	100%	80%	100% of new three-wheelers are electric by 2050.

EV sales mandate for taxis	58% of new taxis are electric by 2050	100%	70%	By 2030, India is aiming for EV sales penetration of 70% for commercial vehicles. This is taken for the low-ambition level, and 100% is assumed by 2050 for the high-ambition level.
EV subsidy: Passenger LDVs, freight LDVs, three-wheelers	The cap on incentives is 20% of the maximum ex-factory price	50%	30%	The cap can be increased to 50%, similar to the incentives in other countries such as Japan[l] for the high-ambition level. For the low-ambition level, it can be marginally increased to 30% over the BAU value.
EV subsidy : Two-wheelers	15% cap according to the new rule effective from June 2023 (*Mint* 2023)	40%	20%	Can be increased to 40% in accordance with old rules for the high-ambition level and to at least 20% for the low-ambition level.[m]
EV subsidy : Passenger HDVs	The cap on incentives for passenger HDVs (classified as e-buses) under FAME II is 40% of the maximum ex-factory price	40%	40%	The cap can remain the same because e-buses are likely to be cost-effective even without a subsidy.[n]
Feebates	Nil	30%	50%	50% of global best practice[o] is taken for the high-ambition level in line with the long-term decarbonization scenario and 30% for the low-ambition level in line with the Nationally Determined Contributions-Sustainable Development Goals (NDCs-SDGs) linkages scenario modeled using the EPS. The global best practice feebate rate results in a fee of approximately INR 75,000 on a vehicle that consumes 12 liters per 100 km, assuming that the pivot point is 10 liters per 100 km.
Hydrogen sales targets	Nil	Buses: 5% Rail: 25% Freight HDVs and shipping: 25%	**Nil,** assuming hydrogen does not become financially viable at the low-ambition level	These targets are in line with the long-term decarbonization scenario developed using the EPS.[p] Fuel cell electric vehicle (FCEV) adoption is sensitive to capital costs, utilization rate, fuel price, and discount rates. For buses, with declining battery costs, electric vehicles (EVs) are likely to be competitive with internal combustion engine (ICE) variants by 2030. By 2050, FCEVs could start competing with EVs in terms of cost owing to a decrease in capital costs, particularly for fuel cells and tank storage, and improvement in the carbon intensity of electricity.[q] Given various ongoing hydrogen buses pilots in Delhi and Chennai, a low target of 5% of buses is assumed for FCEVs by 2050, starting from 2030. Currently, the total cost of ownership of hydrogen passenger vehicles is likely to be higher than that of EVs or ICE vehicles. There is only one four-wheeler model in the Indian market.[r] Hence, no targets are assumed for passenger cars and sports-utility vehicles (SUVs). Rail: 25%. Currently, Indian Railways is planning for 100% electrification by 2030. Moreover, it plans to run 35 hydrogen trains, with the trial planned in 2024.[s] Hence, 25% of new railways can be assumed to be hydrogen powered by 2050. Freight HDVs and shipping: 25%. Hydrogen vehicles are likely to be more popular and cheaper for HDVs than EVs or ICEs for longer distances, given cost decreases and new refueling infrastructure investments.[t]

Note: n/a = not applicable.

Source: a. Climate Trends and JMK Research & Analytics 2022, b. Swamy et al. 2021b, c. Kaur et al. 2022, d. Kumar et al. 2021, e. Ravuri and Aswathy 2022, f. Kumar 2021.
g. Kumar et al. 2022, h. Swamy et al. 2021b, i. Chaturvedi and Malyan 2022, j. PIB 2022d, k. Kumar et al. 2022, l. EVAAP 2023, m. PIB 2022e, n. Nagaraj 2023, o. Swamy et al. 2021b.
p. Swamy et al. 2021b, q. Hall et al. 2020, r. Maitra et al. 2023, s. PIB 2023d, t. Hall et al. 2020.

APPENDIX D. ASSUMPTIONS FOR STRATEGY 3 (MODAL SHIFT)

Table D-1 | **Assumptions for Strategy 3 (modal shift)**

VEHICLE CATEGORY	BUSINESS AS USUAL (BAU)	TARGETS FOR 2050		JUSTIFICATION
		HIGH AMBITION	LOW AMBITION	
Percentage travel demand shifted from passenger cars and taxis to public transport	0	30	15	**High ambition** is based on the sustainable urban mobility scenario described in Dhar et al. (2015). **The low-ambition** value is taken from the Nationally Determined Contributions–Sustainable Development Goals (NDCs-SDGs) linkages scenario, which was 15% by 2030. This value is taken for 2050.
Percentage reduction in travel demand for passenger aircraft	0	10	5	**The high-ambition** value is based on the BLUE Shifts scenario in Cazzola et al. (2009), with a 10% reduction in aircraft use in non-OECD countries by 2050 compared to the BAU value. **The low-ambition value** is taken from the NDCs-SDGs linkages scenario, which was 5% by 2030. This value is taken for 2050.
Percentage travel demand shifted from freight HDVs to freight rail	0	35	10	India has already set an NDC target of 45% mode share for railways by 2030 (PIB 2022f). Hence, the highest value in the EPS (35%) is taken for the **high-ambition level.** **The low-ambition** value is taken from the NDCs-SDGs linkages scenario, which was 10% by 2030. This value is taken for 2050.

ENDNOTES

1. The current version of the India EPS uses growth rates for travel demand and vehicle efficiencies from India Energy Security Scenarios (IESS) version 2. This was updated to the IESS version 3 in late 2023; however, the India EPS has not yet been updated to reflect this in order to include more current assumptions on future transport demand (NITI Aayog 2023).
2. The India EPS includes assumptions about vehicle lifetime, after which they are retired and replaced by new vehicles. The type/efficiency of the replacement vehicle is determined by the policy lever settings of the fuel efficiency standards lever and the EV or hydrogen vehicle (H2V) sales mandate lever, so the replacement vehicle could be either an EV or H2V, or a vehicle with an improved fuel economy. The EPS, however, does not account for pollution due to older vehicles.
3. For more details of how the various model components are implemented, see Energy Innovation Policy & Technology LLC (n.d.).
4. Estimates provided according to the 2018 rate of the Indian rupee: 69.1 INR = 1 US$ (in 2018). https://fedai.org.in/UploadPopupPageFiles/HistoricalExchangeRates_2018-19.pdf.
5. It is essential to note the cost uncertainties of implementing modal shift policies. This is because the India EPS considers the change in the vehicle capital costs and fuel costs; however, it does not attempt to estimate the cost associated with infrastructure investments that may be necessary to support the transition. In addition, the India EPS does not incorporate last-mile connectivity.

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ABOUT WRI INDIA

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org

Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.