DISCUSSION PAPER

India's Crude Oil Imports to 2050 Under Alternative Road Transport Policy Pathways

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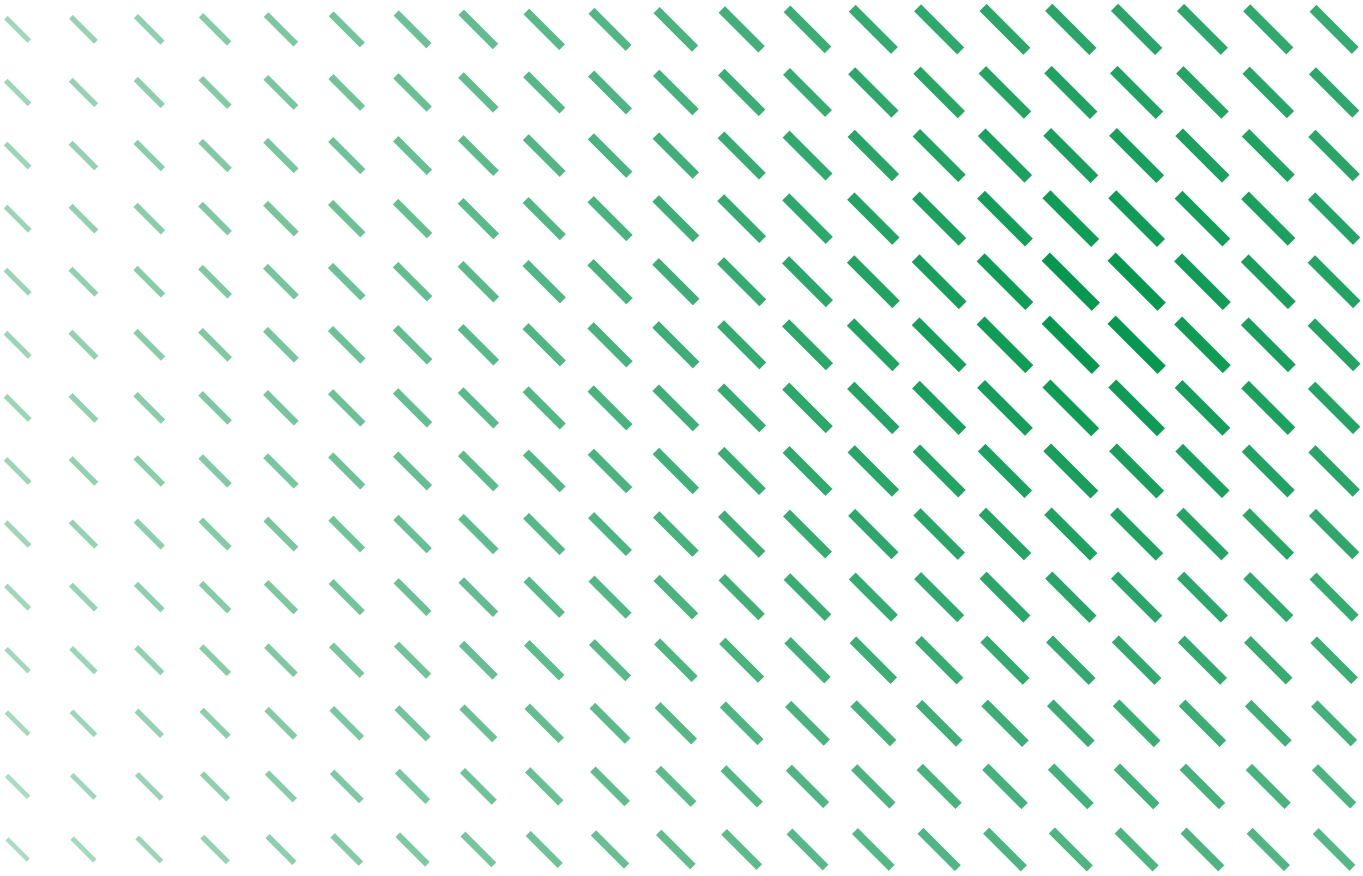

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Key Points

- India's transport policies fall into three groups: demand-side measures, such as electric vehicle (EV) purchase incentives under Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) and Pradhan Mantri Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE); supply-side measures, such as battery manufacturing incentives and biofuel, green hydrogen, and compressed natural gas (CNG) programs; and regulatory measures, such as fuel-economy norms and blending mandates. This study represents these policies through five levers: electrification, hydrogen, fuel economy, biofuel blending, and modal shift.
- Four scenarios apply these levers at different rates: Baseline continues current trends; the Stated Policy Scenario (SPS) meets India's announced targets by 2030-2031; and the Moderate and Aggressive Transition scenarios go beyond those targets and use all five levers progressively faster, with total travel and freight demand the same in all four scenarios, so that differences in results come only from the levers.
- Under current trends, India's oil import dependence deepens, and by financial year (FY) 2050-2051, road transport would need 9.2 million barrels per day (mb/d) of imported crude oil, nearly twice India's total crude-oil imports in FY 2025-2026.
- The five levers together can cut this need by half or more. Combining electrification, hydrogen, fuel economy, biofuel blending, and modal shift lowers road transport's crude-oil import need to between 1.7 and 4.5 mb/d by FY 2050-2051.
- The cumulative savings are large: from FY 2025-2026 to FY 2050-2051, the transition scenarios avoid 21.7-36.1 billion barrels of crude-oil imports, worth $1.3-$3.6 trillion at $60-$100 per barrel.
- Modal shift meets the same passenger and freight demand with fewer vehicles. Although activity grows strongly across all scenarios, shifting travel to buses and rail reduces the 2050-2051 vehicle fleet from 847 million in the Baseline to 648 million under Aggressive Transition – a 24% reduction.
- Modal shift depends on a major rail expansion. Rail freight activity (tonne-kilometers) would need to grow by about 8% a year for three decades.

Abstract

India imported 88.7% of its crude oil in FY 2025-2026, and road transport is a principal driver of this dependence. This study uses the bottom-up TERI Transport Model (TERI-TptM) to project road-transport service demand, vehicle stock, and imported crude-oil requirements to FY 2050-2051 under four scenarios: Baseline, Stated Policy Scenario (SPS), Moderate Transition, and Aggressive Transition. In every scenario, passenger activity grows by 4.2% a year and freight activity by 6.8% a year. The scenarios differ only in five levers: electrification, hydrogen adoption, fuel-economy improvement, biofuel blending, and modal shift from private vehicles to intracity buses and from trucks to rail. The model converts gasoline and diesel demand into an imported crude-oil requirement using refinery yields, allowing domestic crude production to decline. By FY 2050-2051, the vehicle stock reaches 847 million in the Baseline, compared with 734, 695, and 648 million in SPS, Moderate Transition, and Aggressive Transition, respectively. Under the Baseline, road transport would require 9.20 million barrels per day (mb/d) of imported crude oil, nearly twice India's total crude imports in FY 2025-2026. This falls to 4.48, 2.61, and 1.73 mb/d in the three policy scenarios. From FY 2025-2026 to FY 2050-2051, these scenarios avoid 21.7-36.1 billion barrels of crude-oil imports relative to the Baseline, worth $1.3-$3.6 trillion at $60-$100 per barrel. The deepest reductions, however, depend on freight rail growing by about 8% a year for three decades.

Keywords: India; road transport; energy transition; oil-import dependence; scenario analysis; vehicle electrification; decarbonization.

List of Abbreviations

Abbreviation	Full term
2W	Two-wheeler
3W-P	Passenger three-wheeler
4W-C&J	Four-wheelers, cars, and jeeps
4W-Taxi	Four-wheelers, taxis
ACC	Advanced chemistry cell
ASIF	Activity, structure, intensity, and fuel
b/d	Barrels per day
BEV	Battery electric vehicle
BPKM	Billion passenger-kilometers
BTKM	Billion tonne-kilometers
CAFE	Corporate Average Fuel Efficiency
CAGR	Compound annual growth rate
CBG	Compressed biogas
CEEW	Council on Energy, Environment, and Water
CIRT	Central Institute of Road Transport
CNG	Compressed natural gas
CSTEP	Center for Study of Science, Technology and Policy
E20	Petrol blended with 20% ethanol
EV	Electric vehicle
EV30@30	Campaign for a 30% EV share of new vehicle sales by 2030
FAME	Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles in India
FY	Financial year (April to March)
GDP	Gross domestic product
GJ	Gigajoule
GST	Goods and Services Tax
GWh	Gigawatt-hour
H&MPVs	Heavy and medium passenger vehicles
HSD	High-speed diesel
ICCT	International Council on Clean Transportation
ICE	Internal combustion engine
IEA	International Energy Agency
IESS	India Energy Security Scenarios
IMRT	India Multi-Region TIMES model
IPCC	Intergovernmental Panel on Climate Change
KAPSARC	King Abdullah Petroleum Studies and Research Center
LGV	Light goods vehicle
LNG	Liquefied natural gas
MAPE	Mean absolute percentage error
MHGV	Medium and heavy goods vehicle
MoRTH	Ministry of Road Transport and Highways
MoSPI	Ministry of Statistics and Programme Implementation
Mtoe	Million tonnes of oil equivalent
NCV	Net calorific value
NEMMP	National Electric Mobility Mission Plan

Abbreviation	Full term
NITI	National Institution for Transforming India
NRP	National Rail Plan
OECD	Organisation for Economic Co-operation and Development
pkm	Passenger-kilometers
PLI	Production-linked incentive
PM E-DRIVE	Pradhan Mantri Electric Drive Revolution in Innovative Vehicle Enhancement
PNGRB	Petroleum and Natural Gas Regulatory Board
PPAC	Petroleum Planning and Analysis Cell
RMSE	Root mean square error
SATAT	Sustainable Alternative Towards Affordable Transportation
SPS	Stated Policy Scenario
STU	State transport undertaking
TERI	The Energy and Resources Institute
TERI-TptM	TERI Transport Model
TIMES	The Integrated MARKAL-EFOM System
tkm	Tonne-kilometers
toe	Tonne of oil equivalent
TPA	Tonnes per annum
UN DESA	United Nations Department of Economic and Social Affairs
VKM	Vehicle-kilometers

Introduction

01

Road transport is the dominant mode for passenger movement and freight distribution in India. The road network spans approximately 6.7 million kilometers (IBEF 2026), and national highways grew by nearly 60% between 2014 and 2025, from 91,287 km to 146,572 km (Ministry of Road Transport and Highways 2026a).

Initiatives such as the Bharat Mala Pariyojana, the Pradhan Mantri Gati Shakti National Master Plan, and the National Logistics Policy (2022) have supported this expansion, and the road freight sector is now valued at more than $150 billion (NITI Aayog 2026b). The vehicle fleet remains predominantly reliant on petrol and diesel, although CNG, LNG, electricity, and green hydrogen are gaining traction.

In financial year[1] (FY) 2024-2025, road transport accounted for a cumulative 400 million registered vehicles, with annual registrations of approximately 31 million (Ministry of Road Transport and Highways 2026b). As of FY 2025-2026, two-wheelers account for about 72% of all cumulative registered vehicles in the country (Ministry of Road Transport and Highways 2026b).

In FY 2025-2026, passenger cars, including private and utility vehicles, constitute the second-largest vehicle category, accounting for approximately 12%-15% of the total fleet (Ministry of Road Transport and Highways 2026b). Three-wheelers, including auto-rickshaws used for both passenger and light freight services, account for approximately 3%-5% of the vehicle fleet stock. Heavy and medium passenger vehicles (H&MPVs), despite their importance in mass transit, represent a very small share of the total vehicle fleet, generally less than 1%.

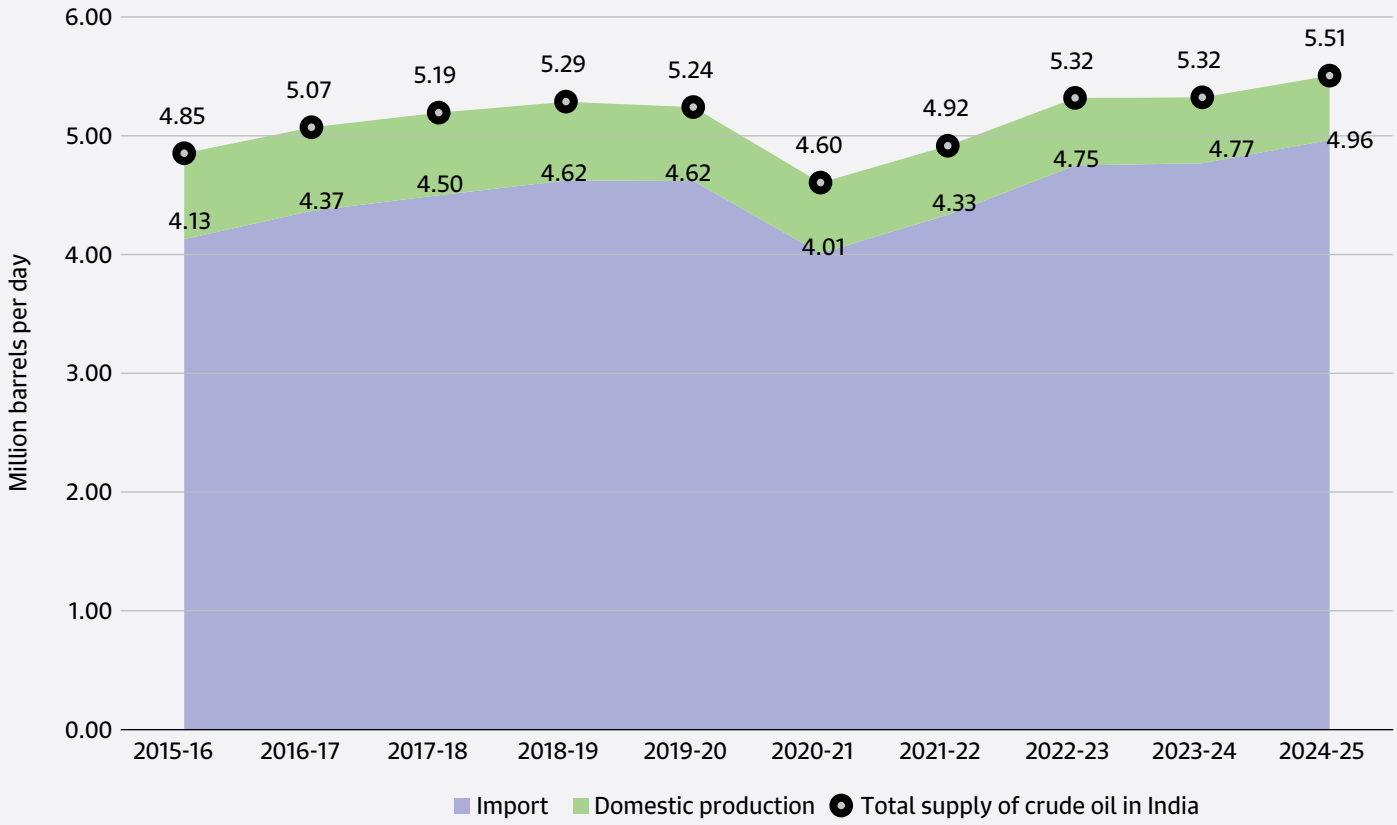
However, their contribution to passenger movement is disproportionately high, as they serve as the backbone of public transport systems across cities and intercity routes. Freight vehicles, including light goods vehicles (LGVs) and medium- and heavy-goods vehicles (MHGVs), together account for about 4%-5% of the total vehicle fleet (Ministry of Road Transport and Highways 2026b).

India's vehicle fleet remains dominated by internal combustion engine technologies. Gasoline is the primary fuel for two-wheelers and passenger cars, while diesel is predominantly used in freight vehicles and buses. The overall fleet remains heavily reliant on fossil fuels, with gasoline vehicle sales accounting for around 80%, diesel for approximately 10%, and electric vehicles (EVs) for about 7.5% in FY 2025-2026 with CNG, LPG, and other fuels accounting for the remaining 2.5% (Ministry of Road Transport and Highways 2026b; NITI Aayog 2026a).

1 The financial year is a 12-month period beginning April 1 and ending March 31 of the following calendar year.

This continued dependence on gasoline and diesel has broader implications for India's energy security because domestic crude oil production has not kept pace with rising petroleum demand. As shown in Figure 1, India has become increasingly reliant on crude oil imports while domestic production has remained stagnant and gradually declined. Between FY 2015-2016 and FY 2024-2025, total crude oil supply for refining (imports plus domestic production) increased from 4.85 to 5.51 million barrels per day (mb/d). Over the same period, crude oil imports rose from 4.13 to 4.96 mb/d, while domestic production declined from 0.72 to 0.54 mb/d. As a result, imports rose from about 85% to 90% of total crude oil supply. while domestic production fell from nearly 15% to below 10%.

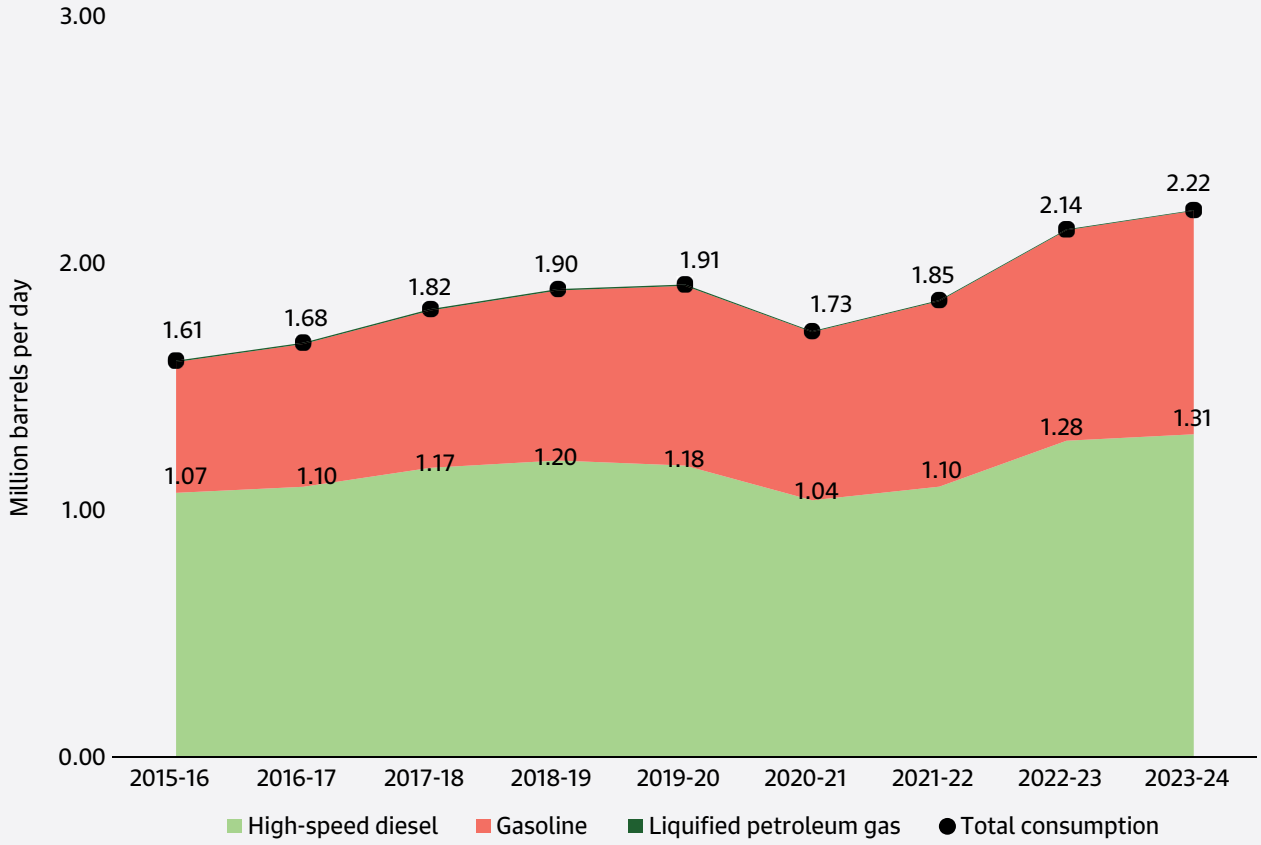
Figure 1. Crude oil supply for refining in India, imports versus domestic production.



Source: Petroleum Planning and Analysis Cell (2025), Import/Export of Crude Oil and Petroleum Products, FY 2024-2025.

In addition, the road transportation in India consumes nearly half of refinery products (by volume) (Kamboj et al. 2022; Mohan et al. 2025). Figure 2 illustrates the breakdown of road transport fuel consumption in India by product, revealing a clear upward trend from FY 2015-2016 to FY 2023-2024 that reflects sustained growth in road transport activity. Total conventional fuel consumption rose from approximately 1.61 to 2.22 million barrels per day, driven by expanding passenger mobility and freight demand. Throughout the period, the fuel mix remained heavily dominated by high-speed diesel (HSD), which consistently accounted for the largest share of total consumption. This underscores freight movement's structural dependence on diesel-powered vehicles. Meanwhile, gasoline consumption has grown faster, driven by rising ownership of two-wheelers and passenger cars.

Figure 2. Petroleum product consumption in India's road transport.



Source: NITI Aayog (2026a), India Climate & Energy Dashboard.

As a result, the road transport sector sits at the intersection of key strategic concerns, including energy security and exposure to global oil price volatility, making reduced oil dependence a strategic priority for India. Policymakers are increasingly focused on diversifying fuel sources, electrifying vehicles, and promoting alternative fuels such as biofuels and green hydrogen (Ministry of Petroleum and Natural Gas 2018a; Ministry of New and Renewable Energy 2023; Ministry of Heavy Industries 2024). These efforts aim not only to reduce greenhouse gas (GHG) emissions but also to enhance long-term energy security.

This study evaluates how alternative transition pathways could reshape India's road-transport energy demand and its exposure to crude-oil imports. It assesses four scenarios: a Baseline that continues existing trends from the FY 2019-2020 base year; a Stated Policy Scenario (SPS) reflecting announced policies and targets; a Moderate Transition with faster uptake of cleaner technologies; and an Aggressive Transition with rapid, large-scale deployment of low-carbon transport. The scenarios differ in EV adoption, hydrogen use, biofuel blending, modal shift, and fuel-efficiency improvements. Oil-import exposure is measured as the imported crude-oil requirement of road transport, derived from gasoline and diesel demand by accounting for refinery yields and domestic crude-oil production.

Existing studies have examined transport decarbonization, electrification, and emissions, but the closest bottom-up studies (Section 3) stop at fuel demand or emissions and do not explicitly translate transition pathways into crude-oil import requirements. The analysis uses the same bottom-up modeling framework as The Energy and Resources Institute (TERI) (2024) but asks a different question. TERI (2024) covers road, rail, and aviation, with coastal shipping estimated separately only to 2030, measures GHG emissions, and uses six scenario runs; this study focuses on road transport and exposure to crude-oil imports, and uses a Baseline and three transition scenarios so that the differences between scenarios remain easy to trace.

The remainder of the paper is organized as follows. Section 2 reviews India's road-transport policies, Section 3 describes the modeling framework and scenario design, Section 4 presents the results, and Section 5 concludes.

Road Transport Policy Landscape in India

02

2.1 Policy Instruments

India's clean road transport policy combines demand-side incentives, supply-side support, and regulatory measures across electrification, alternative fuels, domestic manufacturing, and enabling infrastructure.

On the demand side, the National Electric Mobility Mission Plan (NEMMP) laid the foundation for vehicle electrification. It was implemented through the Faster Adoption and Manufacturing of (Hybrid & Electric) Vehicles in India (FAME) schemes, phases I and II, which funded EV purchases and charging infrastructure (Ministry of Heavy Industries 2012, 2015, 2019). More recently, the Pradhan Mantri Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme aims to scale EV deployment across vehicle segments (Ministry of Heavy Industries 2024). Lower Goods and Services Tax (GST) rates and income-tax incentives further improve EV affordability (Ministry of Finance 2019).

On the supply side, production-linked incentive (PLI) schemes for advanced chemistry cell batteries and automotive components build domestic manufacturing capacity and reduce import dependence for critical technologies (Ministry of Heavy Industries 2021a, 2021b). For alternative fuels, the National Policy on Biofuels promotes ethanol blending, and the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative supports compressed biogas production (Ministry of Petroleum and Natural Gas 2018a, 2018b). The National Green Hydrogen Mission covers hard-to-abate segments, including heavy-duty transport (Ministry of New and Renewable Energy 2023), while an expanding CNG network offers a transitional, lower-emission option for urban transport (Anand and Singh 2024).

Regulation complements these measures. Bharat Stage emission standards, Corporate Average Fuel Efficiency (CAFE) norms, and the vehicle scrappage policy improve fleet efficiency and reduce emissions from conventional vehicles (Ministry of Road Transport and Highways 2021; DieselNet 2018). India has also joined the Clean Energy Ministerial's EV30@30 campaign, which aims for electric vehicles to reach 30% of new vehicle sales by 2030 (Clean Energy Ministerial 2017; NITI Aayog 2025).

EV adoption has progressed most rapidly among three-wheelers and two-wheelers, while electrification of medium- and heavy-duty freight vehicles remains limited. Based on VAHAN registration data for FY 2023-2024, electric vehicles accounted for approximately 49% of three-wheeler registrations, 5% of two-wheeler registrations, and 2% of passenger-car registrations, while their share among trucks remained negligible (Ministry of Road Transport and Highways 2026b). Table 1 summarizes India's road-transport policy landscape.

Table 1. Road transport policy landscape in India.

Policy Name	Key policy levers	Year	Target	Targeted segments	Aim	Source
NEMMP	Roadmap for EV adoption, R&D support, and demand creation	2013	6-7 million EV and hybrid sales by 2020	EV ecosystem (all segments)	Reduce oil imports, promote clean mobility	Ministry of Heavy Industries (2012)
FAME I and II schemes	Purchasing subsidies, charging infrastructure funding	2015, 2019	Support EV adoption and infrastructure rollout	2W, 3W-P, cars, buses	Accelerate EV penetration	Ministry of Heavy Industries (2015, 2019)
Fuel efficiency	Corporate Average Fuel Efficiency (CAFE) norms	2015	Improve vehicular efficiency; CAFE-III tightens fleet targets from 2027-2028 to 2031-2032	ICE vehicles	Reduce energy consumption	Bureau of Energy Efficiency (2024); Ministry of Power (2026)
Emission standards	Leapfrog from BS-IV to BS-VI emission standards	2016	Reduce vehicular emissions	ICE vehicles	Improve air quality	Ministry of Road Transport and Highways (2016)
National Policy on Biofuels	Ethanol blending (E20), biodiesel promotion	2018 (updated 2022)	20% ethanol blending by Ethanol Supply Year (ESY) 2025-2026	Fuel suppliers, transport sector	Reduce crude oil imports and emissions	Ministry of Petroleum and Natural Gas (2018a)
SATAT initiative (CNG/CBG)	Promote compressed biogas production and use	2018	5,000 CBG plants producing 15 MMT of CBG per annum by 2023-2024	Transport fuel ecosystem	Substitute fossil fuels with bio-CNG	Ministry of Petroleum and Natural Gas (2018b)
PLI Scheme	Incentives for battery manufacturing	2021	50 GWh battery manufacturing capacity	Battery manufacturers	Reduce import dependence and localize the supply chain	Ministry of Heavy Industries (2021b)
PLI scheme (automobiles and components)	Incentives for advanced automotive technologies	2021	Promote EV and hydrogen vehicle manufacturing	Auto manufacturers	Boost domestic production and exports	Ministry of Heavy Industries (2021a)
GST reduction on EVs	Tax reduction (12% → 5%)	2019	Lower EV purchase cost	EV consumers	Improve affordability and adoption	Ministry of Finance (2019)
Vehicle scrappage policy	Incentives for scrapping old vehicles	2021	Deregister vehicles that fail mandatory fitness tests for personal vehicles older than 20 years and commercial vehicles older than 15 years	Vehicle owners, fleet operators	Reduce emissions and improve fleet efficiency	Ministry of Road Transport and Highways (2021)
National Green Hydrogen Mission	Incentives for green hydrogen production	2023	5 million tonnes per year green hydrogen production by 2030	Industry and heavy transport	Decarbonize hard-to-abate sectors	Ministry of New and Renewable Energy (2023)
CNG infrastructure expansion	Expansion of city gas distribution networks	Ongoing	18,336 CNG stations by 2032	Urban transport	Promote cleaner gaseous fuels	Ministry of Petroleum and Natural Gas (2024)
PM E-DRIVE	Financial incentives, e-vouchers, and charging infrastructure support	2024	Large-scale EV adoption	2W, 3W, buses, trucks, and ambulances (not private cars)	Scale the EV ecosystem and manufacturing	Ministry of Heavy Industries (2024)

Source: Authors' construction, based on sources stated in the table.

The policies in Table 1 differ in maturity and in the segments they target. Support for electrification has moved from the NEMMP roadmap in 2013, through the FAME schemes in 2015 and 2019, to the PM E-DRIVE scheme in 2024 (Ministry of Heavy Industries 2012, 2015, 2019, 2024), and the GST rate on electric vehicles was reduced from 12% to 5% in 2019 (Ministry of Finance 2019). On the supply side, the PLI schemes target 50 GWh of advanced chemistry cell battery capacity and support the manufacture of electric and hydrogen vehicles (Ministry of Heavy Industries 2021a, 2021b).

Fuel policies set quantified targets: 20% ethanol blending by ESY 2025-2026 under the amended National Policy on Biofuels (Ministry of Petroleum and Natural Gas 2018a), 5,000 compressed biogas plants under SATAT (Ministry of Petroleum and Natural Gas 2018b), and 5 million tonnes per annum of green hydrogen production under the National Green Hydrogen Mission (Ministry of New and Renewable Energy 2023), alongside the expansion of the CNG station network (Anand and Singh 2024). Regulatory measures, namely CAFE norms, Bharat Stage emission standards, and the vehicle scrappage policy, act mainly on the efficiency and age of the internal combustion engine fleet (Bureau of Energy Efficiency 2024; Ministry of Road Transport and Highways 2016; Ministry of Road Transport and Highways 2021).

2.2 Representation of Policies in the Scenarios

The policies in Table 1 are the basis for the five scenario levers described in Section 3. For electrification, the trajectories draw on the demand-side measures that lower the cost of electric vehicles (NEMMP, the FAME schemes, PM E-DRIVE, and reduced GST rates) and on the EV30@30 commitment.

For hydrogen, the National Green Hydrogen Mission guides the shares assumed for buses and for medium- and heavy-goods vehicles. CAFE norms set the direction of the fuel-economy trajectories. For biofuel blending, the National Policy on Biofuels and the SATAT initiative underpin the ethanol, biodiesel, and CBG assumptions. For modal shift, the National Rail Plan motivates the move of freight to rail. Its target rail share of freight is substantially higher than any scenario assumes (Ministry of Railways 2022). Separately from the five levers, the expansion of the CNG network guides the shares of gaseous fuels.

The SPS reflects targets announced up to 2030-2031, including the EV30@30 sales goal and the ethanol, biodiesel, and CBG blending targets. The Moderate and Aggressive Transition scenarios extend these policies beyond their current targets.

Two policies are not represented. Bharat Stage emission standards are excluded because they regulate pollutant emissions, not fuel use. The vehicle scrappage policy is not modeled explicitly because retirement is represented through a fixed average vehicle life for each category (Section 3.1). More generally, each lever is specified as an exogenous trajectory. Policies therefore affect the results only through the assumed parameter values; the model does not simulate the policy instruments themselves.

Modeling Framework and Scenario Design

03

This study employs the TERI Transport Model (TERI-TptM), a bottom-up framework for estimating domestic road transport demand across passenger and freight segments (TERI 2024). The model follows a sequential, demand-driven approach to estimating transport requirements for individual vehicle categories.

The model then aggregates these vehicle-level estimates to derive total passenger and freight transport demand, expressed in billion passenger-kilometers (BPKM) and billion tonne-kilometers (BTKM), respectively. Passenger transport is disaggregated into two-wheelers, three-wheelers, cars and jeeps, taxis, and buses, while freight transport is divided into light goods vehicles and medium- and heavy-goods vehicles. The framework follows five interconnected steps, as summarized in Figure 3.

First, the framework projects key activity drivers, including gross domestic product (GDP), population, and income, over the modeling horizon.

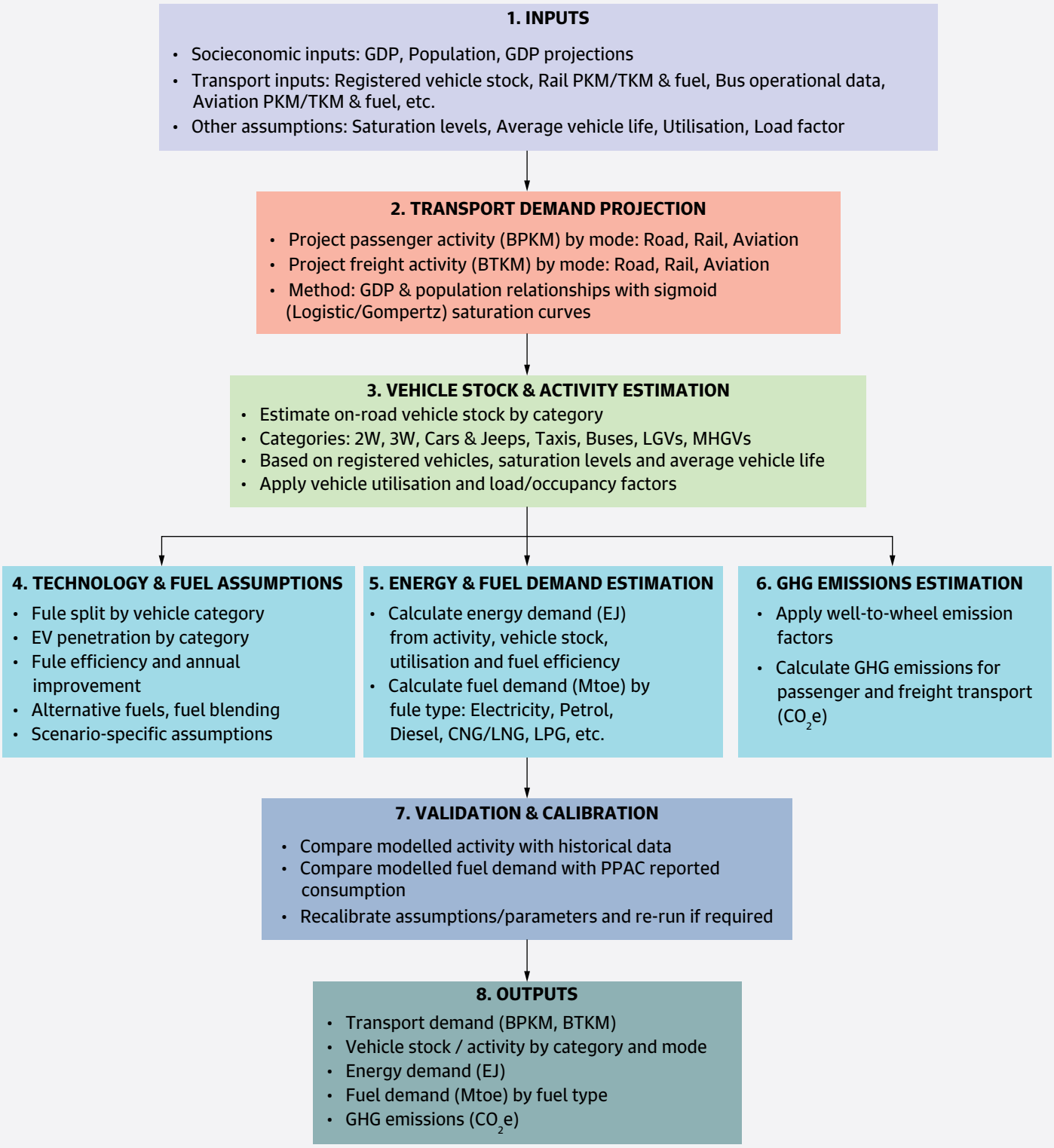
Second, the model estimates vehicle stock by vehicle category and fuel type. The model derives passenger vehicle stocks using ownership saturation curves and derives freight vehicle stocks in the same way from real GDP, then obtains road freight activity from the stock using utilization and load factors. The model incorporates vehicle retirement through category-specific average vehicle lives (Table A2 in Appendix A).

Third, the model converts on-road vehicle stock to vehicle-kilometers traveled using category-specific annual utilization rates, then to passenger-kilometers and tonne-kilometers using occupancy and load factors.

Fourth, the model allocates vehicle-kilometers across fuels and technologies according to scenario-specific fuel shares, then estimates corresponding fuel demand using fuel-economy assumptions.

Finally, the model converts fuel demand to a common energy basis. Inputs are introduced across the first four steps, as detailed in Appendix Tables A1-A3, while the resulting outputs consist of annual fuel and energy demand by fuel type and vehicle category, which are subsequently used in the oil-import analysis.

Figure 3. Road transport model overview.



Source: Adapted from TERI (2024).

The model is calibrated to the FY 2019-2020 base year by reconciling estimated vehicle stock, transport activity, and fuel use with reported vehicle-registration and fuel-sales data (TERI 2024). This ensures that base-year fuel demand by fuel type is consistent with observed consumption before the projection period begins. Vehicle stock is represented using a vintage-stock approach, in which annual registrations are added to the fleet and retired once they reach the category-specific average vehicle life.

The registered vehicle stock published by the Ministry of Road Transport and Highways (Table A1 in Appendix A) is a cumulative count of registrations that is not adjusted for vehicles that have left the fleet; the model therefore uses it only as an input, and the on-road fleet used in all calculations represents cumulative registrations net of vehicle retirements. For each projection year, new-vehicle requirements are calculated as the difference between the stock required to meet projected activity or ownership levels and the surviving stock from earlier vintages. New sales (gross annual additions to the stock) therefore reflect both growth in transport demand and the replacement of retired vehicles.

Fuel consumption is estimated separately for gasoline, diesel, CNG, LNG, electricity, hydrogen, and blended fuels by applying fuel-economy assumptions to the vehicle-kilometers allocated to each fuel and vehicle category. These estimates are then aggregated to category and sector levels.

Appendix A provides the inputs used at specific stages of the modeling framework. Table A1 lists the sources for macroeconomic, demographic, and vehicle-related parameters used in the stock and activity calculations, including GDP and population trajectories, vehicle-life assumptions, annual utilization, occupancy rates, and load factors. Table A2 provides the saturation levels and density parameters used to define long-term passenger-vehicle ownership trajectories. Table A3 contains the principal scenario assumptions, including fuel-economy improvements, grid fuel mix, EV and hydrogen adoption, modal shift, and fuel-blending assumptions. Together, these inputs determine the model outputs, including transport activity by mode, fuel demand by fuel type, and total energy demand.

Bottom-up vehicle-stock models are widely used to project road-transport energy demand. The present study is most closely related to previous bottom-up assessments of India's road-transport sector, particularly four modeling efforts. It builds most directly on TERI-TptM (TERI 2024), a standalone, demand-driven model based on the ASIF framework (Schipper and Marie-Lilliu 1999) whose low-emission pathways are constructed around technology adoption, biofuel blending, and freight modal shift; the present study extends this design by adding an explicit fuel-economy lever alongside electrification and by carrying the resulting fuel demand through to crude-oil import exposure.

It is also related to CSTEP's India Multi-Region TIMES (IMRT) model (Byravan et al. 2017), a bottom-up framework that evaluates electrification and efficiency measures with an eye to reducing fuel imports, which the present study complements by comparing policy-defined scenarios with progressively stronger levers rather than reporting a single cost-optimized pathway. The ICCT's India Emissions Model (Bansal and Bandivadekar 2013) offers the closest precedent for the underlying stock accounting – deriving fleet composition from new-vehicle sales and age-based survival and vehicle-kilometer curves – but is oriented toward pollutant emissions and control costs; the present study repurposes this stock-turnover logic to estimate fuel demand and oil-import exposure.

Finally, NITI Aayog's India Energy Security Scenarios (IESS 2047) (NITI Aayog 2023) shares a lever-based scenario architecture with road vehicles disaggregated by fuel type, which the present study sharpens into a compact set of separately quantified levers targeted specifically at road-transport oil use.

Its methodological contribution lies in two main areas. First, the study explicitly links projected road-transport fuel demand to India's crude-oil import exposure, extending the analysis beyond energy demand and emissions outcomes. Second, the scenarios are structured around five clearly defined policy levers: electrification, hydrogen adoption, fuel-economy improvement, modal shift, and fuel blending and substitution. This structure makes the assumptions behind each scenario, and their combined effect on oil-import dependence, transparent. These extensions, rather than the underlying vehicle-stock accounting framework, represent the study's principal methodological contribution.

3.1 Key Assumptions

Vehicle stock is estimated across different vehicle categories and fuel types, from which vehicle activity is derived using mode-specific assumptions. Fuel demand is subsequently calculated by applying fuel-efficiency values and technology-specific fuel shares, enabling the estimation of total road transport energy demand for each fuel type.

Modal shift is treated as an exogenous assumption for public transport (buses only) activity, and rail is incorporated into the allocation of projected passenger and freight transport demand across modes. In passenger transport, a higher share of public

transport reduces the passenger-kilometers assigned to private modes such as two-wheelers, cars, and taxis. This lowers private passenger kilometers. Similarly, in freight transport, a higher rail freight share reduces road-based tonne-kilometers, thereby lowering the activity of medium- and heavy-goods vehicles and reducing associated fuel demand and emissions.

The model's base year is FY 2019-2020. This year is selected because FY 2020-2021 and FY 2021-2022 were affected by the COVID-19 pandemic, which disrupted economic activity, travel behavior, freight movement, and vehicle use. Using FY 2019-2020 as the base year helps avoid distortions caused by pandemic-related demand shocks.

The historical modeling period begins in FY 1990-1991, while projections extend through FY 2050-2051. Although the broader TERI-TptM framework can extend to FY 2070-2071, results beyond FY 2050-2051 are more uncertain due to potential technological, behavioral, and policy changes in the transport sector.

The road transport model classifies vehicle categories according to their primary mobility function. Two-wheelers and cars represent private passenger mobility; three-wheelers and taxis capture shared and intermediate mobility; buses represent public transport; light goods vehicles cover smaller freight and last-mile logistics; and medium- and heavy-goods vehicles represent long-distance and bulk freight movement.

The model uses a demand-driven approach, linking road transport demand to macroeconomic, demographic, vehicle-specific, and fuel-specific variables. Key inputs include GDP, population, registered vehicle stock, vehicle saturation levels, average vehicle life, annual vehicle utilization, passenger occupancy, freight load factors, fuel efficiency, fuel shares, and emission factors. Passenger demand is shaped by population, income growth, vehicle ownership, and modal structure, while freight demand is driven by GDP growth, economic activity, logistics demand, and the allocation of freight between road and rail (see Table A1 for assumptions).

To estimate long-term demand, the model uses a saturation-curve approach, drawing on sigmoid functions such as Gompertz and logistic curves, in which vehicle ownership and transport activity grow rapidly during the early stages of economic development but gradually slow and approach saturation as markets mature, incomes rise, and population growth stabilizes. For passenger vehicles, vehicle density is estimated as vehicles per 1,000 population (see Table A2 for assumptions). For freight vehicles, LGV and MHGV densities per 1,000 population are related to real GDP in the same way, and road freight activity is derived from the resulting stock using vehicle utilization and load factors.

Saturation levels define the maximum long-term vehicle density or activity level considered feasible for each vehicle category. In TERI-TptM, the saturation level is the maximum long-run vehicle density for each category, expressed as vehicles per 1,000 population. It is estimated using a sigmoid curve fit, in which ownership rises with economic development and then slows as it approaches saturation, capturing the long-run relationship between vehicle ownership, income, population dynamics, and physical or geographical constraints. Category-specific saturation values are drawn mainly from the literature and stakeholder consultations and are held fixed across scenarios (Table A2).

Vehicle lifetime is handled through an average vehicle-life assumption rather than an explicit time-varying scrappage function and is used to derive in-use stock from cumulative registered stock. Both saturation levels and vehicle-life assumptions are held constant over the simulation period and across scenarios, and Appendix A describes the calibration of the saturation curves and the treatment of vehicle retirement (Table A5). The scenarios differ only in fleet-transition assumptions, chiefly EV penetration, fuel split, and fuel-efficiency improvements, with EV penetration trajectories diverging across the SPS, Moderate Transition, and Aggressive Transition scenarios after 2030-2031.

3.2 Scenario Development

This study develops a baseline scenario alongside three decarbonization scenarios to evaluate alternative transition pathways. These scenarios combine five technology and policy levers, namely electrification, hydrogen adoption, fuel economy, fuel blending and substitution, and modal shift, and are designed to assess the implications for energy security, particularly dependence on crude oil imports.

India's policy landscape provides a strong foundation for these scenarios, with the Government of India promoting biofuel blending, expanding the role of natural gas, and encouraging the adoption of alternative fuel technologies, including BEVs and hydrogen-based solutions. In parallel, improvements in vehicle efficiency and tightening fuel-economy standards are expected to reduce emissions from ICE vehicles while lowering overall energy requirements across transport modes.

The scenarios developed in this study are deterministic policy and technology pathways, not probabilistic forecasts. They compare selected assumptions against a baseline and assess how changes in key parameters affect energy demand and fuel-use outcomes. The main parameters driving the scenario results include vehicle electrification, fuel-efficiency improvement, modal shift in passenger and freight transport, hydrogen penetration, gaseous fuel substitution, and biofuel and CBG blending.

In the model, transport demand is first estimated from macroeconomic and demographic variables, then translated into energy and fuel demand using assumed technology and fuel shares, fuel efficiencies, and vehicle operational characteristics. Each policy lever is implemented as an explicit annual parameter path rather than as a model outcome.

Electrification and hydrogen adoption enter as fuel and technology shares in new vehicle sales that propagate through the stock; fuel-economy improvement enters as category-level efficiency trajectories; fuel blending and substitution enter as blending obligations and gaseous-fuel shares; and modal shift enters exogenously as target public transport shares for passengers and rail shares for freight, which reduce the passenger- and tonne-kilometers assigned to road modes before fuel demand is computed (the modal-shift assumptions are detailed below). Structuring the levers this way makes explicit when each lever enters the fuel-demand calculation.

Table A3 presents the detailed assumptions adopted under each scenario. For each lever, it reports the corresponding value across scenarios, allowing a direct comparison of how the assumptions vary over time and by scenario, with a short rationale clarifying the key differences between the pathways.

In general, the Baseline continues existing trends in fuel economy, grid composition, and technology shares. The Stated Policy Scenario meets announced policy targets by 2030-2031, including the EV30@30 sales goal and the ethanol, biodiesel, and CBG blending targets; it then extends EV, hydrogen, LNG, and CNG adoption and holds biofuel blending constant beyond 2030-2031. The Moderate and Aggressive Transition scenarios share the SPS pathway to 2030–2031 and then assume progressively faster electrification, hydrogen adoption, and modal shift; Moderate Transition also raises biodiesel and CBG blending to 10%, and Aggressive Transition differs from Moderate Transition mainly through faster electrification and hydrogen uptake and a stronger shift to buses and rail, with the same blending levels. Table 2 summarizes these distinguishing features, and Table A3 reports the detailed values.

Under the Baseline scenario, fuel-economy improvement remains at 0.24% per year for lighter vehicles and 0.15% for buses and goods vehicles, while the transition scenarios increase these rates progressively to 0.36% and 0.22% by 2050-2051, respectively. The fossil-fuel share of electricity generation is common across scenarios, declining from 72% in 2020-2021 to 24% in 2050-2051.

EV adoption is a major source of scenario differentiation. By 2050-2051, electrification reaches 9%, 45%, 48%, and 61% for two-wheelers; 21%, 57%, 86%, and 95% for passenger three-wheelers; 6%, 26%, 35%, and 38% for cars and jeeps; and 1.5%, 12%, 17%, and 20% for medium- and heavy-goods vehicles across the Baseline, SPS, Moderate, and Aggressive scenarios, respectively. Hydrogen is introduced only in buses and medium- and heavy-goods vehicles. By 2050-2051, hydrogen shares reach 1.2%, 3.2%, and 4.3% for buses and 2%, 5%, and 10% for heavy goods vehicles under the SPS, Moderate, and Aggressive scenarios.

Fuel blending also increases under the transition scenarios. Ethanol reaches 20%, while biodiesel and compressed biogas reach 5% under the SPS and up to 10% under the Moderate and Aggressive scenarios. Modal shift is represented through public transport and rail shares. By 2050-2051, public transport reaches 13%, 16%, and 20%, while rail freight reaches 30%, 34%, and 38% under the SPS, Moderate, and Aggressive scenarios, respectively. Overall, the scenarios represent progressively stronger electrification, hydrogen uptake, fuel blending, and modal shift beyond the Baseline.

Table 2. Overview of scenarios.

Scenario	Fuel economy improvement	Fossil fuels in the grid	EV adoption	Hydrogen as fuel (bus and MHGV)	Blending target
Baseline	Fixed rate	Declines from 72% (2020-2021) to 24% (2050-2051), common to all scenarios	Low	None	10% ethanol
SPS	Periodic improvement over Baseline	Same as Baseline	Meets 30% annual new vehicle sales target by 2030, higher thereafter	Low adoption	Meets biofuel blending targets by 2030-2031 and continues
Moderate Transition	Same as SPS	Same as Baseline	Meets 30% of target by 2030, higher than SPS thereafter	Low but higher than SPS	Meets biofuel targets by 2030-2031, higher adoption thereafter
Aggressive Transition	Same as SPS	Same as Baseline	Meets 30% of target by 2030, significantly higher than SPS thereafter	Moderate adoption	Same as Moderate Transition scenario

3.3 Limitations

The results should be interpreted in light of several limitations of the modeling framework. First, technology adoption is exogenous. Because adoption is represented through exogenous trajectories, the model does not endogenize the economics of technology choice. It does not model vehicle purchase prices, fuel and running costs, infrastructure requirements, or total cost of ownership, and it does not assume consumers, fleet operators, or other transport users respond to relative costs or affordability. We recognize this as an important limitation, since the relative costs of alternative technologies, particularly electricity and hydrogen, which have historically been more expensive, can influence their affordability and uptake.

The scenarios should therefore be read as policy-conditioned pathways: they estimate the fuel-demand and oil-import implications if the specified levels of technology adoption is achieved, rather than predicting the cost-optimal or affordability-constrained level of adoption: Endogenizing technology costs and affordability is left for future research.

Second, the analysis relies on single-point values for several uncertain parameters, including GDP growth, vehicle-ownership saturation levels, average vehicle life, EV and hydrogen penetration, and the rate of fuel-economy improvement. Saturation levels and vehicle lives are held constant over time and across scenarios (Table A2), and travel and freight demand are common to all scenarios by design, so that the scenarios isolate the effect of the transition levers.

The four scenarios span a wide range of electrification, hydrogen, blending, and modal-shift assumptions and therefore indicate how strongly oil-import exposure responds to the transition levers themselves, and Section 4.4 reports a one-way sensitivity analysis of the remaining parameters. Higher saturation levels would raise vehicle stock and fuel demand in every scenario, mainly in later years, because a higher ceiling makes the sigmoid ownership curve steeper rather than shifting it outward in parallel and slower fleet turnover would delay the effect of new-vehicle technologies on the fleet, so projected exposure levels are likely more uncertain than the differences between scenarios.

Third, validation covers a relatively short period. The model is calibrated to FY 2019-2020, and the comparison with observed diesel plus gasoline demand in Section 4.1 spans nine years, two of them affected by the pandemic. Because modeled demand exceeds observed demand in the two post-pandemic years, projected exposure levels may be somewhat overstated, although the comparison between scenarios is less affected.

Fourth, the crude-oil import indicator allocates crude oil to products using a constant average refinery yield and projects the import share by holding total crude-oil supply at its base-year level. It is attributional and does not model refinery dispatch or trade in petroleum products, so it measures the import exposure embodied in road-fuel demand rather than forecasting national crude-oil imports.

Fifth, the model does not represent land-use planning, compact urban development, or other measures that could reduce travel demand, nor any rebound in travel demand from improved fuel economy, which would make the fuel-economy lever somewhat less effective than estimated here.

Results

04

4.1 Model Validation

Before presenting the scenario results, the model compares its base-year outputs with official statistics. The model is calibrated to FY 2019-2020 by reconciling modeled vehicle stock, transport activity, and fuel use with reported vehicle registrations and fuel sales.

Because the base year is used for calibration, this comparison confirms the starting point of the projections but does not independently test the model's predictive performance, which the following comparison addresses over a longer period. The historical period of TERI-TptM begins in FY 1990-1991 (TERI 2024), which allows modeled road-transport diesel plus gasoline demand to be compared with observed consumption for FY 2015-2016 to FY 2023-2024 from the NITI Aayog India Climate & Energy Dashboard (NITI Aayog 2026a), the series shown in Figure 2. Modeled demand in Mtoe is converted to million barrels per day (mb/d) using the energy content of a tonne of oil equivalent (IEA 2004), the net calorific values of diesel and gasoline (IPCC 2006), and product conversion factors of 7.46 and 8.5 barrels per tonne for diesel and gasoline (bp 2021). Diesel plus gasoline is used because the crude-oil import indicator depends on their combined demand. Table A4 and Figure A1 report the results.

The model tracks observed demand closely in the years before the pandemic, with a mean absolute percentage error (MAPE) of 1.0% for FY 2015-2016 to FY 2018-2019. Across the seven years not affected by the pandemic, the MAPE is 4.5%, and the root mean square error (RMSE) is 0.14 mb/d. As expected, the largest deviations occur in FY 2020-2021 and FY 2021-2022, when pandemic restrictions reduced travel and freight activity, a shock the model is not designed to represent. In FY 2022-2023 and FY 2023-2024, modeled demand remains 10% to 13% above observed demand, which partly reflects the gradual post-pandemic recovery of road-fuel consumption. Because this deviation applies to the activity path common to all scenarios, it mainly affects projected exposure levels rather than the comparison between scenarios.

If the post-pandemic difference were assumed to persist in the same proportion across all scenarios, the Baseline requirement in FY 2050-2051 would be 8.1 to 8.4 mb/d instead of 9.20 mb/d, still well above India's crude-oil imports in FY 2025-2026, and the imports avoided by Aggressive Transition would be 32 to 33 billion barrels instead of 36.1 billion barrels, with the ranking of the scenarios unchanged. The study's main findings therefore hold under this adjustment.

4.2 Road Transport Service Demand and Vehicle Stock

India's road transport sector is expected to undergo a substantial transformation over the coming decades, driven by rapid urbanization, rising incomes, expanding freight movement, and increasing demand for personal mobility. At the same time, the sector remains central to national energy security and decarbonization objectives, given its continued

dependence on petroleum-based fuels and its growing contribution to final energy demand and emissions. In this context, analyzing the evolution of service demand and vehicle stock across alternative scenarios provides important insight into how policy interventions, technology adoption, and modal shift assumptions may influence the scale and structure of India's future transport system.

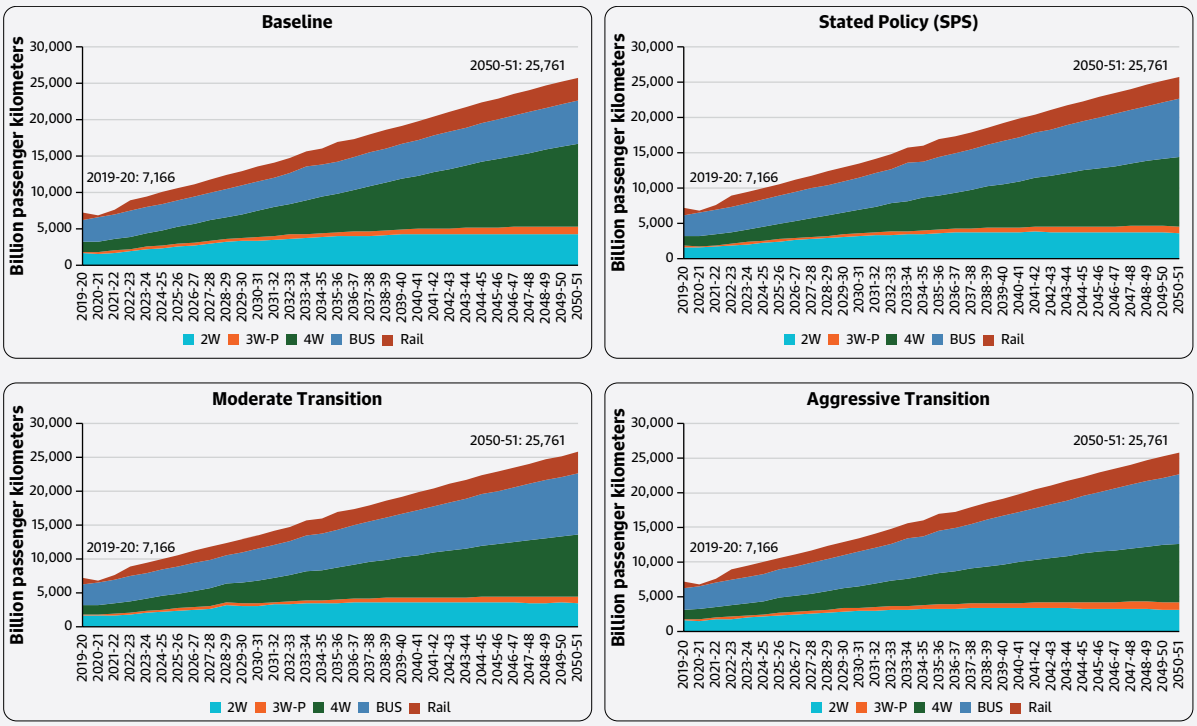
As shown in Figures 4 and 5, passenger and freight service demand are projected to grow substantially over the study horizon, but the four scenarios differ almost entirely in modal composition rather than in aggregate activity. Total passenger demand rises from 7,166 billion passenger-kilometers (pkm) in 2019-2020 to approximately 25,760 billion pkm in 2050-2051, a compound annual growth rate (CAGR) of 4.2% that is common to all scenarios; total freight demand grows more rapidly, from 2,682 billion tonne-kilometers (tkm) in 2019-2020 to about 20,630 billion tkm in 2050-2051, a CAGR of 6.8% that is effectively invariant across scenarios. Aggregate demand is therefore exogenous in this framework, and the scenarios operate as levers on the modal split.

As shown in Figure 4, all scenarios share a common modal structure only in the 2019-2020 base year, in which buses are the dominant mode at 2,940 billion pkm (41.0%), followed by two-wheelers (2W) at 1,583 billion pkm (22.1%), four-wheelers (4W) at 1,307 billion pkm (18.2%), rail at 1,069 billion pkm (14.9%), and three-wheelers (3W-P) at 267 billion pkm (3.7%). Passenger rail is held constant across all four scenarios, rising to 3,132 billion pkm by 2050-2051 at a CAGR of 3.5%; because this is slower than total demand growth, its share declines to about 12% in every case, so rail does not differentiate the scenarios. The passenger transition is therefore a road-based contest, driven mainly by the balance between four-wheelers and buses.

The Baseline describes a car-dominated pathway. Four-wheeler activity grows faster than any other passenger mode, from 1,307 to 11,278 billion pkm (7.2% CAGR), and its share more than doubles from 18.2% to 43.8%, displacing the bus as the largest passenger mode. Over the same period, the bus share contracts from 41.0% to 23.0% (2,940 to 5,936 billion pkm; 2.3% CAGR) and the two-wheeler share declines from 22.1% to 16.5% (1,583 to 4,258 billion pkm; 3.2% CAGR), while three-wheelers grow to 1,157 billion pkm (4.5% share).

The transition scenarios progressively redistribute this road activity from private vehicles (mainly cars) to buses. The 2050-2051 four-wheeler share falls from 43.8% in the Baseline to 37.9% under SPS, 35.7% under Moderate Transition, and 32.5% under Aggressive Transition (11,278 to 8,372 billion pkm across the two extremes). The bus share rises in steps, from 23.0% in the Baseline to 31.8%, 34.9%, and 38.7%, with bus activity in 2050-2051 increasing from 5,936 to 9,969 billion pkm between the Baseline and Aggressive Transition. The two-wheeler share declines steadily across the scenario range, from 16.5% to 12.3%.

Figure 4. Passenger modal shift across scenarios, FY 2019-2020 to FY 2050-2051.



Note: Passenger rail comprises suburban, non-suburban, and metro (Delhi Metro and Kolkata Metro only) services and high-speed rail.

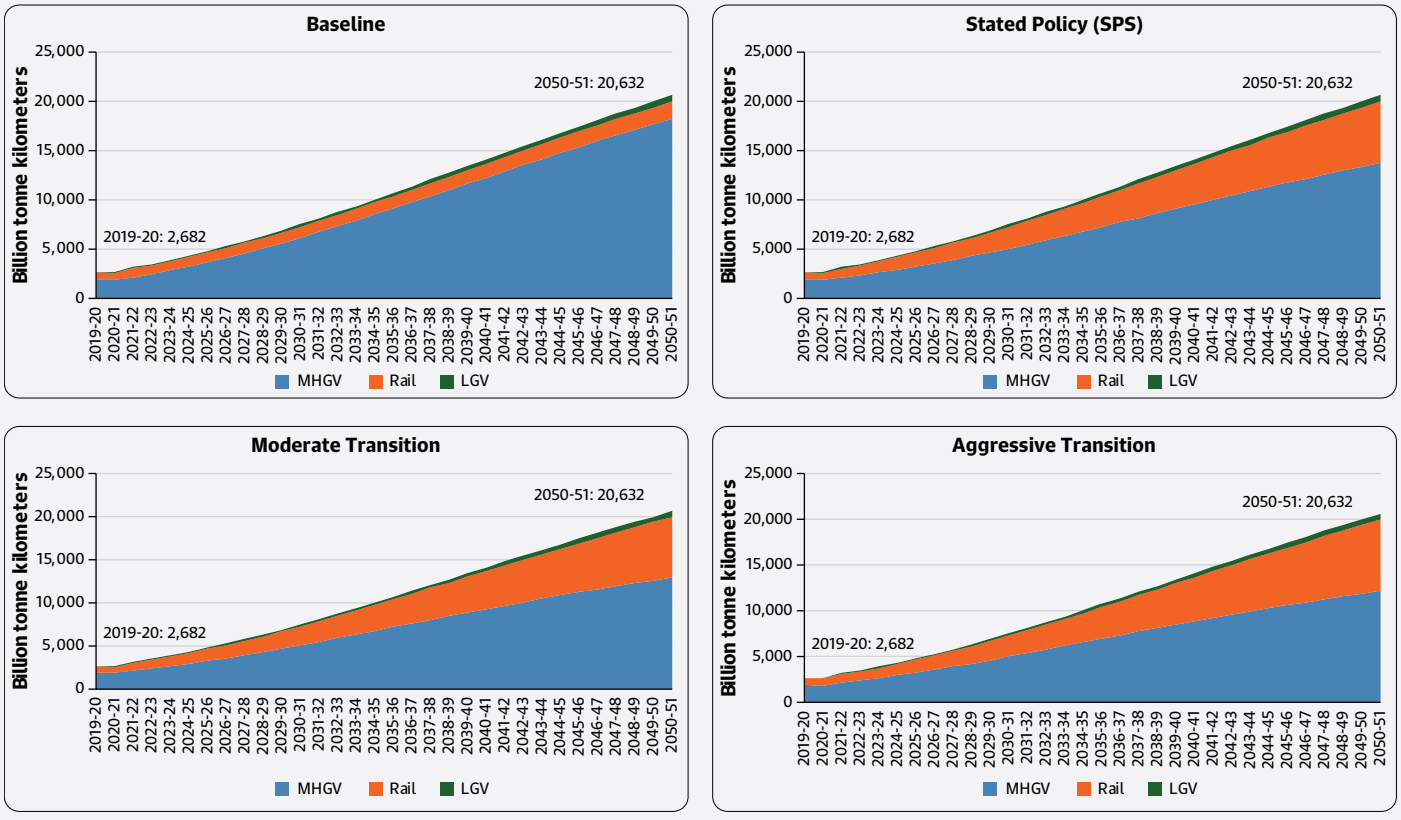
Source: Modeling results and the author's illustration.

The freight results exhibit the largest modal movements in the analysis (Figure 5). All scenarios share a common 2019-2020 structure, with medium and heavy goods vehicles (MHGV) carrying 1,846 billion tkm (68.8%), rail 708 billion tkm (26.4%), and light goods vehicles (LGV) 128 billion tkm (4.8%). LGV activity is identical across scenarios, rising to 660 billion tkm by 2050-2051 (5.4% CAGR) and falling to 3.2% of total freight in every case, so the freight split depends entirely on the balance between MHGV and rail.

In the Baseline, road haulage absorbs almost all incremental demand. MHGV activity grows from 1,846 to 18,216 billion tkm (7.7% CAGR) and its share rises from 68.8% to 88.3%, while rail grows only to 1,762 billion tkm (3.0% CAGR) and its share falls from 26.4% to 8.5%. This decline in rail share is the most pronounced modal shift in either the passenger or freight system, and it runs counter to decarbonization objectives.

The transition scenarios reverse this trend with increasing intensity. Rail is the fastest-growing freight mode under every transition case, with its 2050-2051 share reaching 30.0% under SPS (6,191 billion tkm; 7.3% CAGR), 34.0% under Moderate Transition (7,017 billion tkm; 7.7% CAGR), and 38.0% under Aggressive Transition (7,843 billion tkm; 8.1% CAGR). The MHGV share falls correspondingly, from 88.3% in the Baseline to 66.8%, 62.8%, and 58.8% respectively, with activity reduced from 18,216 to 12,130 billion tkm between the Baseline and Aggressive Transition. Rail freight activity under the ambitious cases therefore reaches between 3.5 and 4.5 times the Baseline level by 2050-2051.

Figure 5. Freight modal shift across scenarios, FY 2019-2020 to FY 2050-2051.



Source: Modeling results and the author's illustration.

Box 1. Modal Shift and Vehicle Stock: The Benefits and Challenges of Transition

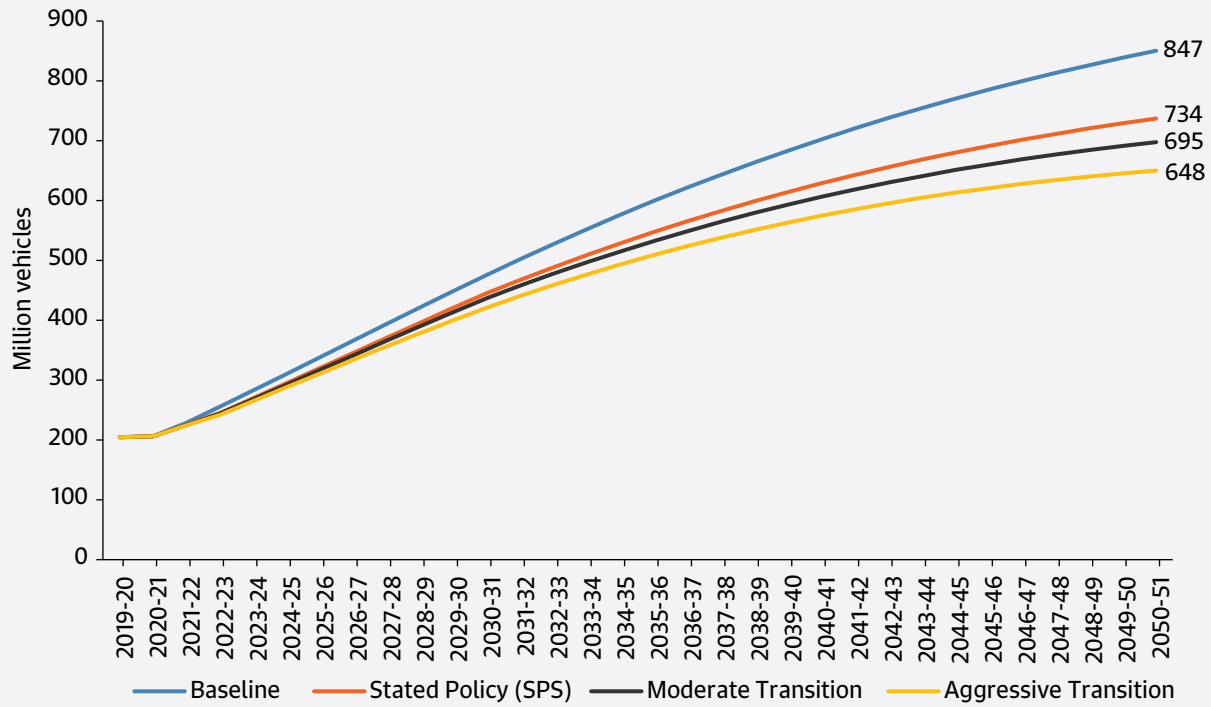
Modal shift plays a role in the transition. For passengers, the shift is from private vehicles (mainly cars) to buses, with rail playing no differentiating role across scenarios. For freight, the shift is from trucks to rail. Both shifts strengthen as policy ambition increases. The most demanding element of the Aggressive Transition scenario is freight rail, which would need to grow by about 8% a year for three decades to raise its share from about 26% to 38% by 2050-2051. This exceeds Indian Railways' highest growth of 7% a year, achieved during 2000-2001 to 2009-2010 (Chakraborty and Prakash 2024), and would require a major build-out of all rail freight capacity and diversification beyond bulk commodities, making it the main practical challenge for this pathway.

Vehicle stock, unlike service demand, differs across scenarios. All four scenarios start from the same fleet of 204 million vehicles in 2019-2020 and stay close through 2020-2021, but they diverge steadily once policy measures take effect. By 2050-2051, the fleet reaches 847 million vehicles in the Baseline, 734 million under the Stated Policy Scenario, 695 million under Moderate Transition, and 648 million under Aggressive Transition, growing at 4.7%, 4.2%, 4.0%, and 3.8% per year, respectively. In other words, the more ambitious the scenario, the smaller the fleet: by mid-century, it is about 13% below the Baseline under SPS, 18% below under Moderate Transition, and 24% below under Aggressive Transition, the last amounting to 199 million fewer vehicles.

Most of this growth comes early. Stock expands at roughly 7% to 8% a year up to 2030-2031 and then slows to between 2% and 3% a year thereafter. Because the transition scenarios both start from a lower level and level off sooner, the gap with Baseline keeps widening, from 54 million vehicles in 2030-2031 to 199 million by 2050-2051.

This is simply the fleet-side reflection of the modal shifts discussed above. Since every scenario has to move the same number of people and goods, meeting that demand increasingly through buses rather than cars, and rail rather than trucks, means fewer vehicles are needed, because buses and rail carry far more traffic per vehicle. As a result, the ambitious scenarios deliver the same transport service with a much smaller fleet, which in turn eases pressure on vehicle manufacturing, materials demand, and end-of-life vehicle flows, depending on the extent of the modal shift.

Figure 6. Vehicle stock projections across scenarios, 2019-2020 to 2050-2051.



Source: Modeling results and the author's illustration.

> The transition delivers the same mobility and freight service with a materially smaller vehicle fleet.

Taken together, the service demand and vehicle stock results point to a clear division in how the transition unfolds. Total travel and freight activity grow strongly to mid-century and are essentially the same in every scenario, so the scenarios do not change how much movement takes place, only how it is delivered. The entire policy signal is reflected in the modal mix. On the passenger side, the shift runs from private vehicles (mainly cars) to buses. On the freight side, the shift runs from trucks to rail. Both shifts deepen as ambition rises from the Stated Policy Scenario to Aggressive Transition.

Vehicle stock is where the consequences of these shifts become visible. Because the same service demand can be met with fewer vehicles once buses and rail carry a larger share, the fleet shrinks steadily as ambition increases, ending almost a quarter smaller under Aggressive Transition than under the Baseline. The transition therefore delivers the same mobility and freight service with a materially smaller vehicle fleet, easing downstream pressure on manufacturing, materials, and end-of-life vehicle flows.

4.3 Energy Security and Crude Oil Imports

Reducing India's dependence on imported crude oil is a key motivation for decarbonizing road transport. This section develops an explicit indicator of road transport's crude-oil import exposure by translating projected gasoline and diesel demand into the corresponding crude-oil import requirement across the four policy scenarios. Rather than treating refined-product demand in barrels of oil equivalent as representative of crude requirements, the indicator accounts explicitly for refinery conversion and domestic crude production.

The indicator is built in four steps (Equations B8 to B14 in Appendix B, and parameters in Table 3). First, fossil gasoline and diesel demand from TERI-TptM, in million tonnes of oil equivalent (Mtoe), is converted to product mass using the energy content of a tonne of oil equivalent and the net calorific value of each fuel (IEA 2004; IPCC 2006).

Second, product mass is converted to a crude-oil equivalent using a refinery product yield of 0.933 tonnes of product per tonne of crude oil processed, the factor applied by the Petroleum Planning and Analysis Cell in its official statistics (Petroleum Planning and Analysis Cell 2026b). Because refining is a joint-production process, dividing the demand for each product by that product's own yield share would assign the full crude input to every product and count the same crude oil more than once; crude oil is therefore allocated to products in proportion to their mass.

Third, the crude-oil equivalent is multiplied by the share of crude-oil supply that is imported. This share starts at 88.7% in FY 2025-2026, the provisional import dependence (PPAC 2026), and to 94.3% by FY 2050-2051 as domestic production continues to decline at its historical rate of 2.67% a year (PRS Legislative Research 2026). Total crude supply is held at its base-year level, so the projected import share is conservative: any growth in refinery throughput would reduce the domestic share further. Applying the average import share is also conservative for avoided imports, because reductions in demand would in practice fall almost entirely on imported crude.

Fourth, the imported requirement is converted to barrels at 7.33 barrels per tonne (PPAC 2026b).

Annual flows are reported in million barrels per day (mb/d) and cumulative flows over FY 2025-2026 to FY 2050-2051 in billion barrels; 1 mb/d sustained for a year equals 365 million barrels. For scale, India imported 245.8 million tonnes of crude oil, about 4.94 mb/d, in FY 2025-2026 (PPAC 2026a). Because the model projects road-transport demand rather than India's overall oil balance, this figure is a scale reference, not a projection of road transport's share of future national imports. India's refining capacity, which exceeds domestic petroleum demand, is discussed within the results section.

Table 3. Parameters used to estimate the crude oil import requirement of road transport.

Parameter	Value	Source
Energy content of one tonne of oil equivalent	41.868 GJ/toe	IEA (2004)
Net calorific value, diesel	43.0 GJ/tonne	IPCC (2006)
Net calorific value, gasoline	44.3 GJ/tonne	IPCC (2006)
Refinery product yield	0.933 tonne of product per tonne of crude	PPAC (2026b)
Crude-oil volume conversion	7.33 barrels per tonne	PPAC (2026b)
Crude-oil import dependence, FY 2025-2026 (provisional)	88.7%	PPAC (2026a)
Compound annual growth rate of domestic crude-oil production, 2014–2023	–2.67%	PRS Legislative Research (2026)
Crude-oil imports, FY 2025-2026	245.8 million tonnes	PPAC (2026a)
Crude-oil price (sensitivity)	$60, $80, and $100 per barrel	Authors' assumption

Note: Sensitivity case holds domestic crude-oil production constant, which keeps the import share at 88.7% throughout the projection period.

Source: Author's construction, based on the sources stated in the table.

As shown in Figures 7 and 8 and Table 4, road transport's imported crude-oil requirement in 2024-2025 ranges from 2.16 mb/d under Aggressive Transition to 2.60 mb/d under the Baseline, equivalent to 44% to 53% of India's crude-oil imports in FY 2025-2026. Under the Baseline, the requirement rises steadily to 9.20 mb/d by 2050-2051 and exceeds the entire current volume of crude-oil imports from 2033-2034 onward.

The Stated Policy Scenario roughly halves this outcome, with the requirement reaching 4.48 mb/d by 2050-2051. Moderate Transition holds the requirement between 2.6 mb/d and 2.8 mb/d from the early 2030s, peaking at 2.80 mb/d in 2036-2037, whereas Aggressive Transition peaks at 2.65 mb/d in 2033-2034 and then declines to 1.73 mb/d by 2050-2051, about 35% of current crude-oil imports.

Table 4. Imported crude-oil requirement of road transport, mb/d (ratio to FY 2025-2026 crude-oil imports).

Year	Baseline	SPS	Moderate Transition	Aggressive Transition
2024-2025	2.60 (53%)	2.38 (48%)	2.17 (44%)	2.16 (44%)
2030-2031	4.12 (84%)	3.31 (67%)	2.57 (52%)	2.57 (52%)
2035-2036	5.53 (112%)	3.85 (78%)	2.79 (56%)	2.64 (53%)
2040-2041	6.94 (141%)	4.17 (84%)	2.71 (55%)	2.32 (47%)
2045-2046	8.17 (165%)	4.46 (90%)	2.77 (56%)	2.16 (44%)
2050-2051	9.20 (186%)	4.48 (91%)	2.61 (53%)	1.73 (35%)

Source: Modeling results. Ratios are relative to observed crude-oil imports in FY 2025-2026 (245.8 million tonnes) and are a scale reference rather than projected shares of future national imports.

From 2025-2026 to 2050-2051, road transport requires 58.4 billion barrels of imported crude oil under Baseline, compared with 36.6 billion barrels under SPS, 25.3 billion under Moderate Transition, and 22.2 billion under Aggressive Transition (Table 5). Relative to the Baseline, the three policy scenarios avoid 21.7, 33.1, and 36.1 billion barrels of crude-oil imports, respectively. At crude-oil prices of $60 to $100 per barrel, the avoided import bill ranges from $1.30 to $2.17 trillion under SPS, $1.99 to $3.31 trillion under Moderate Transition, and $2.17 to $3.61 trillion under Aggressive Transition, undiscounted (Figure 8).

> From 2025 to 2050, the three policy scenarios avoid 21.7, 33.1, and 36.1 billion barrels of crude-oil imports relative to the Baseline.

Because the Baseline represents a high-demand counterfactual, the savings are also measured against SPS, which reflects already announced policies. On this more conservative basis, Moderate and Aggressive Transition avoid a further 11.4 and 14.4 billion barrels, worth about $0.91 trillion and $1.15 trillion at $80 per barrel.

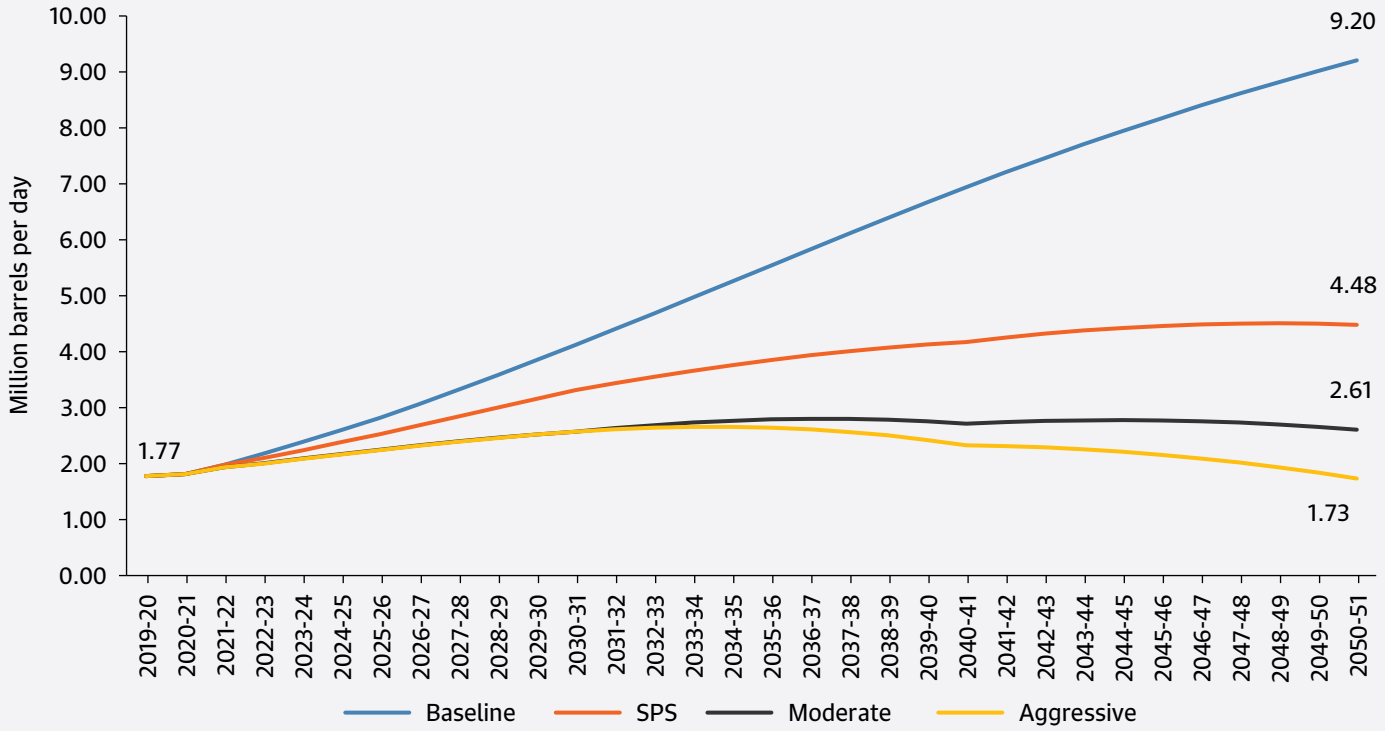
Table 5. Cumulative imported crude-oil requirement and avoided imports, 2025-2026 to 2050-2051.

Scenario	Imported crude oil (billion barrels)	Avoided relative to Baseline (billion barrels)	Avoided import bill relative to Baseline ($ trillion)	Avoided relative to SPS (billion barrels)
Baseline	58.4	–	–	–
SPS	36.6	21.7	1.30–2.17	–
Moderate Transition	25.3	33.1	1.99–3.31	11.4
Aggressive Transition	22.2	36.1	2.17–3.61	14.4

Notes: Avoided import bills are shown for crude-oil prices of $60 to $100 per barrel and are undiscounted. Holding domestic crude-oil production constant reduces the cumulative imported crude-oil requirement by 3% to 4% in every scenario.

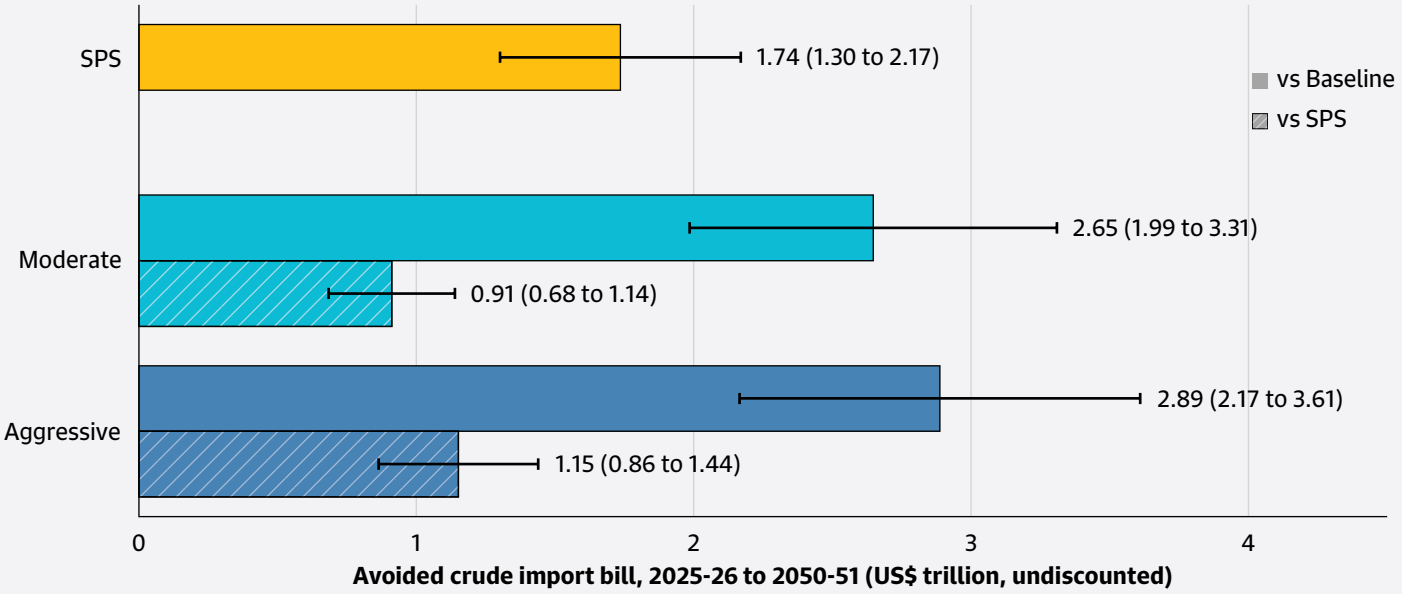
Source: Authors (modeling results).

Figure 7. Imported crude-oil requirement of road transport across scenarios, 2019-2020 to 2050-2051.



Source: Authors (modeling results).

Figure 8. Avoided cumulative crude-oil import bill across scenarios, 2025-2026 to 2050-2051.



Note: Bars show the cumulative avoided bill at $80 per barrel, and whiskers range from $60 to $100 per barrel, measured against the Baseline (solid) and against SPS (hatched).

Source: Authors (modeling results).

> The long-run reduction in crude-oil import exposure depends on sustained policy effort beyond 2030-2031.

Two features stand out. First, Moderate and Aggressive Transition produce almost identical import requirements until the mid-2030s, so the Aggressive Transition pathway's additional security benefit materializes mainly after 2040-2041. The long-run reduction in exposure therefore depends on sustained policy effort beyond 2030-2031. Second, the results are insensitive to assumptions about domestic crude oil production because domestic crude oil meets only about one-tenth of refinery requirements even in the base year. Gasoline and diesel demand levels dominate import exposure.

Box 2. Crude-Oil Import Exposure: Why the Indicator Matters

The indicator is attributional: it measures the imported crude oil embodied in domestic road-fuel demand, with crude oil allocated to products in proportion to their mass. It does not estimate the change in national crude-oil imports that would follow a change in demand. The distinction matters for India, which processes more crude oil than its domestic product demand requires and exports a substantial share of its diesel and gasoline output. If refiners maintain throughput as domestic demand falls, they would export some of the avoided demand rather than translate it into lower crude-oil purchases. The effect on the trade balance would be of comparable magnitude, because product exports earn foreign exchange, but physical crude oil imports would fall by less than the indicator implies.

The results should therefore be read as the import exposure attributable to road transport under each scenario, not as forecasts of national crude oil imports. In addition, the refinery yield is held at its current value, a single barrel-per-tonne factor is applied to all crude oil, and the monetary estimates use constant prices without discounting; they indicate the scale of exposure rather than forecast the import bill.

4.4 Sensitivity and Uncertainty Analysis

The scenario results rest on single-point values for several uncertain parameters. Demand drivers such as GDP and population are common to all scenarios by design, so this section focuses on parameters that govern fleet evolution and technology adoption, along with the import indicator parameters. Each parameter is varied in turn over a plausible range while all others are held at their central values. Saturation levels are scaled by 0.8 and 1.2; average vehicle lives are shortened and lengthened by three years; EV stock shares after 2030-2031 are scaled by 0.75 and 1.25; and the annual rate of fuel-economy improvement is scaled by 0.5 and 1.5.

For the import indicator, refinery yield varies from 0.90 to 0.95, and domestic crude-oil production is held at its FY 2025-2026 level instead of declining. For each case, Table 6 and Figure 9 report the imported crude-oil requirement in FY 2050-2051 under the Baseline and Aggressive Transition, and the cumulative imports avoided under the Aggressive Transition relative to the Baseline from FY 2025-2026 to FY 2050-2051.

The indicator parameters have a small effect. Because the requirement is inversely proportional to the refinery yield, a yield of 0.90 raises it by 3.7% and a yield of 0.95 lowers it by 1.8% in every scenario and year, so the Baseline requirement in FY 2050-2051 ranges from 9.03 to 9.53 mb/d and cumulative avoided imports range from 35.5 to 37.5 billion barrels. Holding domestic production constant lowers the FY 2050-2051 requirement by about 6% and the cumulative requirement by 3% to 4%, reducing avoided imports from 36.1 to 34.6 billion barrels.

The fuel-economy case can be evaluated directly because in TERI-TptM fuel economy affects fuel use but not vehicle activity: liquid-fuel demand in each year is inversely proportional to the cumulative stock-level improvement given in Table A3. Halving the improvement rates raises the FY 2050-2051 requirement by 2.9% under the Baseline and 3.5% under Aggressive Transition, and increasing them by half lowers it by 2.8% and 3.3%, respectively; cumulative avoided imports range from 35.4 to 36.8 billion barrels. These values weigh the bus and goods-vehicle rates by the diesel share of base-year product mass (65%) and the light-vehicle rates by the gasoline share; applying either set of rates alone changes the FY 2050-2051 results by 2.3 to 4.7%.

The EV and vehicle-life cases are estimated from the stock shares in Table A3 and the central model results rather than from new model runs. Each category's diesel plus gasoline demand is taken to be proportional to the share of its stock that uses liquid fuel, weighted by the category's share of road diesel plus gasoline use from the most recent PPAC end-use survey (PPAC 2022), with goods-vehicle diesel divided between MHGVs and LGVs in a ratio of three to one. Scaling EV stock shares after 2030-2031 by 0.75 and 1.25 changes the FY 2050-2051 requirement by about 2% under the Baseline, where EV shares are low, and by 16% to 17% under Aggressive Transition, to between 1.46 and 2.02 million b/d; cumulative avoided imports range from 35.4 to 36.9 billion barrels.

For vehicle life, EV sales shares consistent with the Table A3 stock shares are first derived under the central lives; holding these sales shares constant, shorter or longer lives change the rate at which EVs replace conventional vehicles in the stock. Shortening all lives by three years lowers the Aggressive Transition requirement in FY 2050-2051 to 1.62 mb/d, and lengthening them raises it to 1.76 million b/d, with avoided imports of 35.8 to 36.5 billion barrels.

These estimates assume that activity grows at the same rate in every vehicle category and that each category's stock follows the total fleet path of its scenario (Figure 6). They are not sensitive to the weighting: using the end-use shares of the earlier 2012-2013 survey (PPAC 2014; IEA 2020), dividing goods-vehicle diesel equally or nine to one between MHGVs and LGVs, or raising the weight of goods vehicles by half while reducing that of two-wheelers by a quarter, and the reverse, changes the Aggressive Transition requirement in the EV and vehicle-life cases by at most 0.09 million b/d and cumulative avoided imports by at most 0.2 billion barrels.

The derived EV sales shares reproduce the Table A3 stock shares exactly for every category except passenger three-wheelers, whose EV share approaches 95% and is matched within 5 percentage points; three-wheelers account for about 1% of road diesel plus gasoline use. The 2020-2021 survey period was affected by the pandemic, which reduced bus use, and this is one reason for testing the earlier weights.

Table 6. One-way sensitivity of the imported crude-oil requirement and avoided imports to key parameters.

Parameter	Low/high setting	Baseline, FY 2050-2051 (million b/d)	Aggressive Transition, FY 2050-2051 (million b/d)	Avoided imports, FY 2025-2026 to 2050-2051 (billion barrels)
Central case		9.20	1.73	36.1
Saturation levels (outer bound)	×0.8 / ×1.2	≥7.36 / ≤11.04	≥1.38 / ≤2.08	≥28.9 / ≤43.4
Average vehicle lives	−3 / +3 years	9.14 / 9.22	1.62 / 1.76	36.5 / 35.8
EV stock shares after 2030-2031	×0.75 / ×1.25	9.34 / 9.05	2.02 / 1.46	35.4 / 36.9
Fuel-economy improvement rate	×0.5 / ×1.5	9.46 / 8.94	1.79 / 1.67	36.8 / 35.4
Refinery yield	0.90 / 0.95	9.53 / 9.03	1.80 / 1.70	37.5 / 35.5
Domestic crude-oil production	Constant	8.66	1.63	34.6

Notes: Values are given for the low and high settings, in that order; the domestic production case has one setting. Avoided imports are those of Aggressive Transition relative to the Baseline. All cases other than the central case are derived from the central run and the Table A3 assumptions as described in the text; the saturation row gives outer bounds.

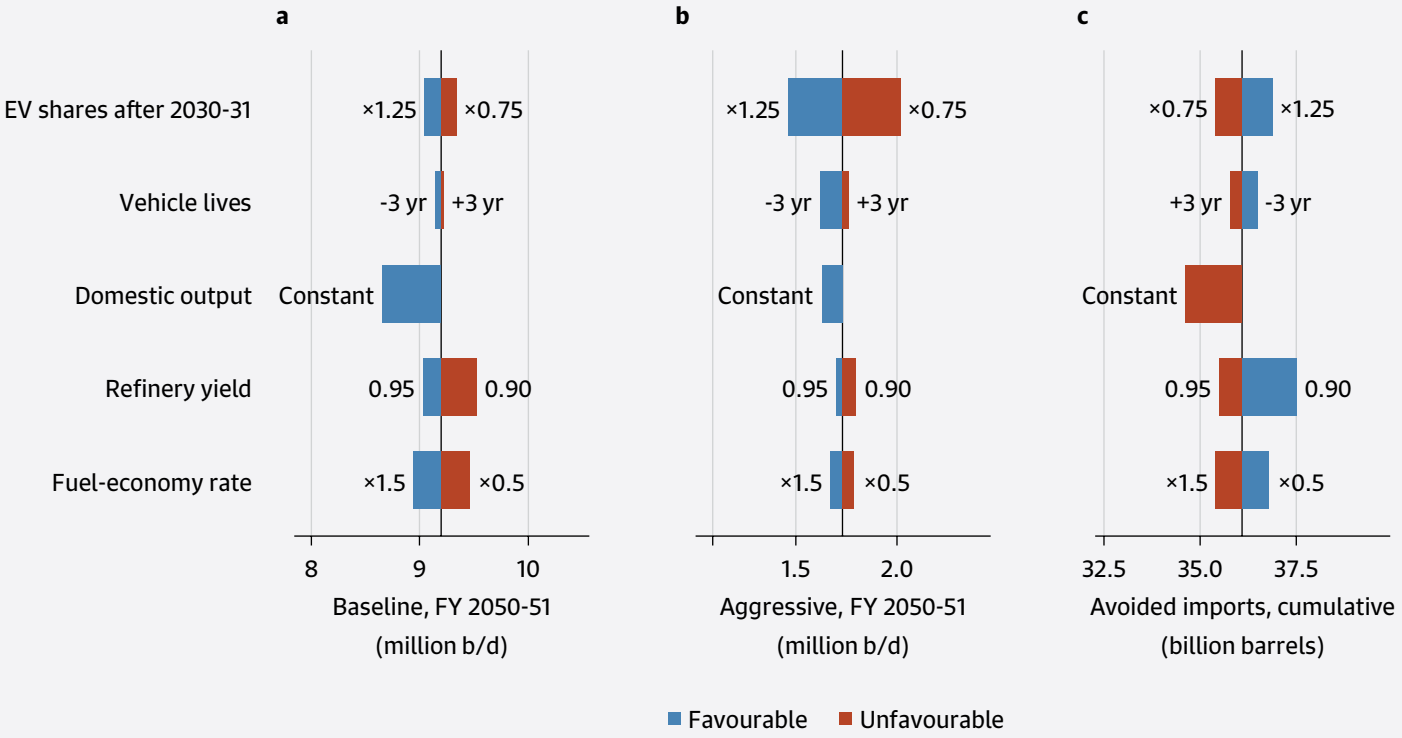
Source: Authors (modeling results).

Saturation levels cannot be varied without refitting the ownership curves, so an outer bound is reported instead. Scaling the saturation levels by 0.8 or 1.2 can change a category's stock, and hence its fuel demand, by at most the same factor, and by less where vehicle densities in FY 2050-2051 remain below saturation. The Baseline requirement in FY 2050-2051 therefore lies within 7.4 b/d to 11.0 million b/d and cumulative avoided imports within 28.9 to 43.4 billion barrels; because the scaling applies to every scenario, it cannot change their ranking.

Across all cases, the ranking of the scenarios is unchanged. Among the cases estimated directly, EV adoption has the largest effect on the transition scenarios, while the indicator parameters and fuel economy matter more for the Baseline. Because the model does not represent vehicle and fuel prices, the EV-share case also indicates how the results would change if relative prices led to faster or slower electrification than assumed.

The margins between scenarios in the central case are wide: in FY 2050-2051, the Baseline requirement is more than twice that of SPS, SPS exceeds Moderate Transition by 72%, and Moderate Transition exceeds Aggressive Transition by 51%. The narrowest margin is between the cumulative requirements of Moderate and Aggressive Transition, 25.3 and 22.2 billion barrels, so this comparison is the most sensitive to the pace of electrification after 2030-2031.

Figure 9. One-way sensitivity of the imported crude-oil requirement in FY 2050-2051 and of cumulative avoided imports.



Notes: a: Baseline requirement in FY 2050-2051. b: Aggressive Transition requirement in FY 2050-2051. c: Imports avoided by Aggressive Transition relative to the Baseline, FY 2025-2026 to FY 2050-2051. Bars show the change from the central case (vertical line); red marks higher import exposure and blue lower, and labels give the parameter setting. Saturation levels are not shown because only an outer bound is available (Table 6).

Source: Authors (modeling results).

We chose a one-way analysis rather than a full probabilistic analysis because each TERI-TptM run solves the complete stock-turnover model, and because the literature has not established joint probability distributions for these parameters in India. The one-way ranges show the response to each parameter but not to their combination, so the combined uncertainty in projected levels is potentially greater than any single bar in Figure 9. The fuel-economy, EV, and vehicle-life cases are derived from model outputs and the Table A3 assumptions, and the saturation case is a bound; full runs of TERI-TptM for each case would refine these estimates.

Conclusion

05

This study examines how alternative road-transport transition pathways could affect India's future mobility system and its exposure to imported crude oil.

Across all scenarios, passenger and freight activity continue to expand strongly through FY 2050-2051. The principal differences arise from how this activity is served: stronger shifts toward buses and rail reduce reliance on private cars and road freight, lowering the vehicle stock from 847 million vehicles in the Baseline to 648 million under Aggressive Transition by mid-century (a 24% reduction).

These structural changes translate into substantial differences in crude-oil import exposure. The imported crude requirement attributable to road transport rises to 9.20 mb/d under the Baseline by FY 2050-2051, compared with 4.48 mb/d under SPS, 2.61 mb/d under Moderate Transition, and 1.73 mb/d under Aggressive Transition. These are 51%, 72%, and 81% below the Baseline, respectively.

Cumulatively, the three transition scenarios avoid 21.7-36.1 billion barrels (37%-62% of the Baseline requirement of 58.4 billion barrels) of imported crude relative to the Baseline over FY 2025-2026 to FY 2050-2051. At crude prices of $60-$100 per barrel, these reductions correspond to avoided import expenditure of approximately $1.30-$3.61 trillion, depending on the pathway and price assumption. The comparison also shows that the additional energy-security benefit of the Aggressive Transition pathway emerges mainly after FY 2040-2041, because the Moderate Transition and Aggressive Transition scenarios follow similar trajectories through the mid-2030s. This finding emphasizes the importance of sustained implementation rather than near-term ambition alone.

At the same time, lower petroleum dependence does not eliminate external energy-security risks: greater use of LNG and electrification can shift exposure toward international gas markets, battery supply chains, and critical minerals.

The results should therefore be interpreted as policy-conditioned scenarios rather than forecasts. Technology adoption, modal shift, fuel economy, and several other parameters are imposed exogenously, and the crude-oil indicator is attributional rather than a forecast of national crude imports. Subject to these limitations, the analysis demonstrates that a coordinated strategy combining electrification, efficiency improvement, alternative fuels, and modal shift can materially reduce India's road-transport exposure to imported crude oil while meeting rapidly growing mobility and freight demand.

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Appendices

Appendix A. Model Development

Table A1. Key input variables.

Input variable	Role in the model	Source
GDP	Drives passenger and freight transport demand	National Accounts Statistics, MoSPI; OECD long-term GDP projections
Population	Used to estimate vehicle density and passenger mobility demand	UN DESA population projections
Registered vehicle stock	Base for estimating road vehicle stock	MoRTH (2026b)
Road transport – operational characteristics of buses	Estimates bus vehicle-kilometers, stock, fuel use, and energy demand	Central Institute of Road Transport (2022)
Indian Railways – Passenger kms (PKM), tonne kms (TKM), fuel consumption, traction shares	Used to assess road-to-rail modal shift.	Ministry of Railways (2022)
Vehicle saturation levels	Defines long-term upper bounds for vehicle density	Hossain et al. (2023); Singh et al. (2020); Arora et al. (2011); Kumar Singh (2006). Average vehicle life and annual utilization: TERI (2024).
Average vehicle life	Used to estimate the on-road vehicle stock from the registered stock	
Annual utilization	Converts stock into vehicle activity	

Source: Authors' compilation from the sources listed in the table.

Table A2. Assumed saturation levels and average vehicle life.

Vehicle category	Saturation level (vehicles per 1,000 population)	Average vehicle life, years
Two-wheelers	300	10
Three-wheelers	50	12
Cars and jeeps	200	15
Taxis	20	12
Buses	3	15
Light goods vehicles	25	15
Medium- and heavy-goods vehicles	25	15

Source: Authors, with saturation levels based on Hossain et al. (2023), Singh et al. (2020), Arora et al. (2011), and Kumar Singh (2006), and cross-checked through stakeholder consultations, and with average vehicle lives from TERI (2024).

Table A3. Detailed assumptions for all scenarios.

Policy lever	Parameter (unit)	Segment	2020-2021	Baseline			SPS			Moderate Transition			Aggressive Transition			Rationale / distinguishing characteristics
				2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	
Fuel-economy improvement	Annual mileage improvement in stock (% per year)	2W	0.24%	0.24%	0.24%	0.24%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	Baseline continues the historical efficiency-improvement rate. The three transition scenarios adopt a common accelerated rate from 2030-2031, reflecting tightening fuel-economy standards. Fuel economy is not differentiated among the three transition scenarios.
		3W-P	0.24%	0.24%	0.24%	0.24%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	
		4W-C&J	0.24%	0.24%	0.24%	0.24%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	
		4W-Taxi	0.24%	0.24%	0.24%	0.24%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	0.30%	0.30%	0.36%	
		Bus	0.15%	0.15%	0.15%	0.15%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	
		LGV	0.15%	0.15%	0.15%	0.15%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	
		MHGV	0.15%	0.15%	0.15%	0.15%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	0.17%	0.17%	0.22%	
Grid fossil-fuel share	Fossil-fuel share in ex-bus generation (% of generation)	All modes	72.0%	58.0%	26.0%	24.0%	58.0%	26.0%	24.0%	58.0%	26.0%	24.0%	58.0%	26.0%	24.0%	Held common across all scenarios so that differences in transport emissions reflect transport choices rather than power-sector assumptions. The pathway follows the national grid-decarbonization trajectory.
EV adoption	Electrification of stock (% of vehicle stock)	2W	0.5%	2.5%	5.3%	9.3%	15.0%	33.6%	45.3%	15.0%	36.6%	47.7%	15.0%	38.6%	60.7%	Primary differentiator across scenarios. All scenarios share the same stock share through 2030-2031, consistent with announced targets, and diverge thereafter. Aggressive Transition assumes the fastest deployment, while Baseline continues current adoption trends.
		3W-P	0.6%	5.6%	12.6%	21.0%	22.6%	45.9%	56.8%	22.6%	48.6%	86.0%	22.6%	51.5%	95.2%	
		4W-C&J	0.2%	0.8%	2.2%	6.2%	4.2%	14.2%	26.5%	4.2%	18.6%	34.9%	4.2%	21.0%	38.2%	
		4W-Taxi	0.4%	3.7%	9.3%	14.9%	9.4%	30.0%	45.9%	9.4%	36.0%	51.5%	9.4%	36.0%	66.5%	
		Bus	0.3%	0.8%	1.6%	2.3%	6.4%	15.5%	25.4%	6.4%	18.9%	33.7%	6.4%	23.3%	40.3%	
		LGV	0.6%	2.5%	6.1%	10.1%	3.5%	12.0%	17.7%	3.5%	13.6%	25.5%	3.5%	17.0%	34.0%	
		MHGV	0.1%	0.3%	0.6%	1.5%	1.8%	6.0%	11.6%	1.8%	8.2%	17.1%	1.8%	9.0%	20.4%	

Table A3. Detailed assumptions for all scenarios (Continued)

Policy lever	Parameter (unit)	Segment	2020-2021	Baseline			SPS			Moderate Transition			Aggressive Transition			Rationale / distinguishing characteristics
				2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	2030-2031	2040-2041	2050-2051	
Hydrogen (buses and MHGV)	Hydrogen vehicles in stock (% of vehicle stock)	Bus	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%	1.2%	0.1%	1.0%	3.2%	0.1%	2.0%	4.3%	Applied only to buses (fuel-cell) and MHGV (hydrogen ICE), where battery-electric options are more constrained. Zero in Baseline, with uptake beginning after 2030-2031 and rising fastest under Aggressive Transition.
		MHGV	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	2.0%	0.5%	2.1%	4.9%	0.5%	4.0%	9.9%	
Fuel blending and substitution	Ethanol blending in petrol pool (%)	—	10.0%	10.0%	10.0%	10.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	Baseline holds current blend levels. Ethanol reaches the 20% (E20) limit in all transition scenarios, as higher blends require flex-fuel engines. Biodiesel and CBG deepen to 5%-10%, with biodiesel constrained near 10% by feedstock availability and CBG scalable through distributed biogas plants.
	Biodiesel blending in diesel pool (%)	—	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%	5.0%	5.0%	5.0%	10.0%	5.0%	5.0%	10.0%	
	CBG blending in CNG (%)	—	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%	5.0%	5.0%	5.0%	10.0%	5.0%	5.0%	10.0%	
Modal shift	Public-transport (intracity buses) share of passenger travel (%)	—	8.0%	6.0%	5.0%	5.0%	9.0%	11.0%	13.0%	10.0%	13.0%	16.0%	12.0%	16.0%	20.0%	Baseline continues the historical decline in public-transport and rail shares. The transition scenarios reverse this trend, with the public transport and rail-freight shares rising progressively and most strongly under Aggressive Transition.
	Railway share of freight (%)	—	27.6%	14.9%	10.0%	8.5%	29.0%	29.0%	30.0%	29.0%	31.0%	34.0%	30.0%	34.0%	38.0%	

Note: Under the National Policy on Biofuels, a 20% ethanol blending target is set for 2025-2026; however, blending beyond this level is not considered, as it would require large-scale deployment of flex-fuel engines. The policy also specifies a 5% biodiesel blending target by 2030, although its potential is expected to remain below 10% due to feedstock constraints. In addition, a 5% CBG blending obligation is envisaged from 2028-2029 onward, with significant potential arising from decentralized, small-scale biogas plants operating at the micro level.

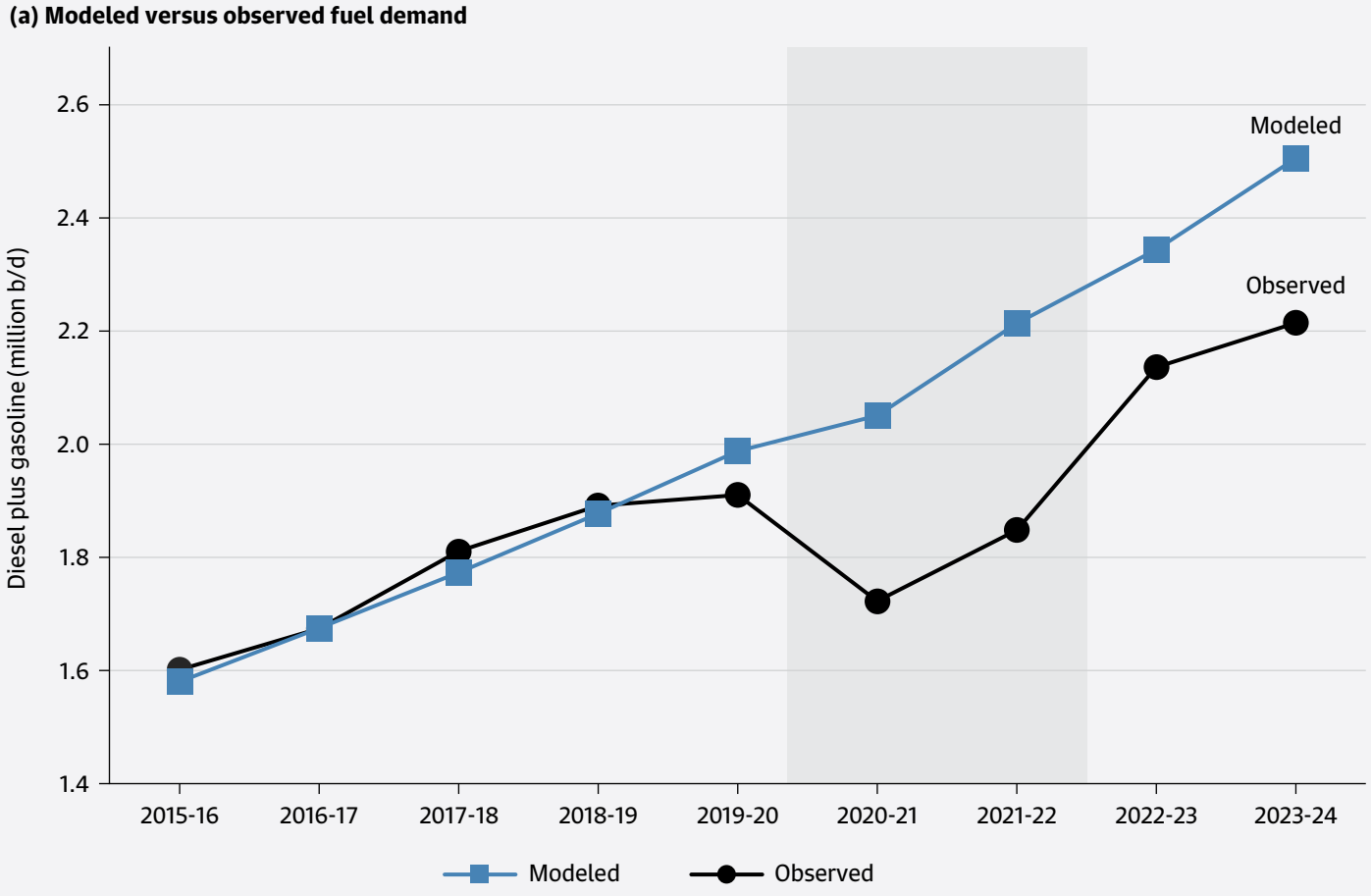
Table A4. Historical validation of modeled road-transport diesel plus gasoline demand, FY 2015-2016 to FY 2023-2024.

Sample	Years	MAPE (%)	Mean bias (%)	Mean bias (million b/d)	RMSE (million b/d)
All years, FY 2015-2016 to FY 2023-2024	9	7.8	+6.8	+0.13	0.20
Excluding pandemic years	7	4.5	+3.3	+0.07	0.14
Pandemic years, FY 2020-2021 and FY 2021-22	2	19.4	+19.4	+0.35	0.35
Before the base year, FY 2015-2016 to FY 2018-2019	4	1.0	−1.0	−0.02	0.02
After the pandemic, FY 2022-2023 and FY 2023-2024	2	11.5	+11.5	+0.25	0.25

Notes: Errors are modeled minus observed diesel plus gasoline demand, in million b/d of product; a positive bias means the model overestimates. Modeled demand is converted from Mtoe using IEA (2004), IPCC (2006), and BP (2021) factors. MAPE: mean absolute percentage error. RMSE: root mean square error.

Source: Modeled values from TERI-TptM; observed values from NITI Aayog (2026a).

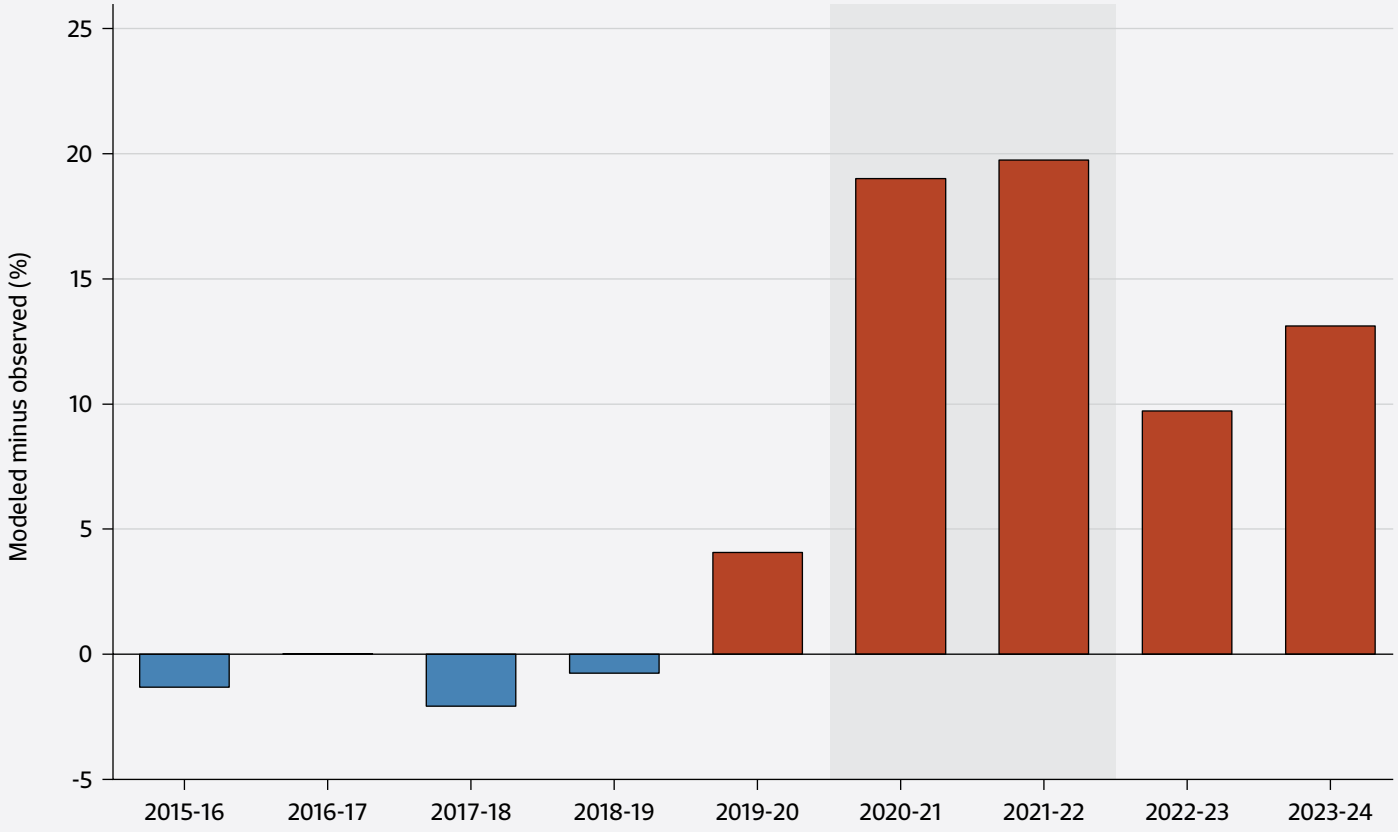
Figure A1. Modeled and observed road-transport diesel plus gasoline demand, FY 2015-2016 to FY 2023-2024.



Note: a: diesel plus gasoline demand, million b/d. b: Difference between modeled and observed diesel plus gasoline demand, percent; red marks overestimation, and blue marks underestimation. Shading marks the pandemic-affected years FY 2020-2021 and FY 2021-2022.
Source: TERI-TptM modeling results; NITI Aayog (2026a); the author's illustration.

Figure A1. Modeled and observed road-transport diesel plus gasoline demand, FY 2015-2016 to FY 2023-2024 (continued).

b) Percentage deviation of modeled from observed demand



Note: a: diesel plus gasoline demand, million b/d. b: Difference between modeled and observed diesel plus gasoline demand, percent; red marks overestimation, and blue marks underestimation. Shading marks the pandemic-affected years FY 2020-2021 and FY 2021-2022.

Source: TERI-TptM modeling results; NITI Aayog (2026a); the author's illustration.

Vehicle stock is calibrated by vehicle category (TERI 2024). For each road category, vehicle density per 1,000 population is related to real GDP per capita for passenger vehicles and to real GDP for freight vehicles, using sigmoid (logistic or Gompertz) curves bounded by the saturation levels in Table A2. The curves are fitted to historical on-road stock derived from MoRTH registration data, real GDP at 2011-2012 prices from the National Accounts Statistics (Ministry of Statistics and Programme Implementation 2023) and population from UN DESA (2023), and projected with long-term real GDP growth from OECD (2021) and UN DESA population projections.

The historical series are closely associated: the correlation between GDP per capita and vehicle density is 0.99 for two-wheelers, 0.96 for passenger three-wheelers, 0.99 for cars and jeeps, 0.98 for taxis, and 0.88 for buses, and the correlation between GDP and vehicle density is 0.98 for LGVs and 0.94 for MHGVs (TERI 2024). Table A5 summarizes the calibration for each category.

The long-run trajectories are governed mainly by the saturation levels, which are taken from the literature and stakeholder consultations rather than estimated (Table A2), and the fitted curves operate jointly with the other model components. Their combined performance is therefore assessed by comparing modeled and observed diesel plus gasoline demand in Section 4.1 (Table A4 and Figure A1), and the effect of the saturation levels on the results is bounded in Section 4.4.

Table A5. Calibration of road vehicle-ownership saturation curves.

Vehicle category	Variable	Saturation (per 1,000)	Life (years)	Correlation
Two-wheelers	GDP per capita	300	10	0.99
Passenger three-wheelers	GDP per capita	50	12	0.96
Cars and jeeps	GDP per capita	200	15	0.99
Taxis	GDP per capita	20	12	0.98
Buses	GDP per capita	3	15	0.88
Light goods vehicles	GDP	25	15	0.98
Medium- and heavy-goods vehicles	GDP	25	15	0.94

Notes: The variable is the explanatory variable of the saturation curve; saturation is in vehicles per 1,000 population; life is the average vehicle life. Correlation coefficients are between the historical series of the explanatory variable and vehicle density; they measure association and are not goodness-of-fit statistics of the fitted curves. The dependent variable is vehicles per 1,000 population in every category. Saturation levels and average lives are from Table A2.

Source: TERI (2024).

Vehicle retirement is not represented by a fitted scrappage curve. On-road stock in each year equals the registrations of the preceding years up to the category-specific average vehicle life in Table A2, so each vintage is retired when it reaches that life. The average life represents the period during which an average vehicle remains in use for technical or policy reasons, and it is held constant throughout the simulation period and is identical across the four scenarios (TERI 2024). Because no scrappage curve is estimated, the sensitivity of the results to vehicle life is assessed directly in Section 4.4, where all lives are shortened and lengthened by three years.

Appendix B. Model Equations

Vehicle activity is defined as the annual vehicle-kilometers traveled by each mode, obtained by multiplying on-road vehicle stock by average annual utilization:

$$VKM_m = Stock_m \times UTIL_m \quad \text{(B1)}$$

where *VKM_m* is the annual vehicle-kilometers traveled for mode *m*, *Stock_m* is the on-road vehicle stock for mode *m*, and *UTIL_m* is the average annual distance traveled per vehicle, in vehicle-kilometers per vehicle per year. On-road vehicle stock is derived from cumulative registrations using the category-specific average vehicle lives in Table A2, which account for the difference between the cumulative number of registered vehicles and the number of vehicles operating on roads. For passenger transport, vehicle-kilometers are converted into passenger-kilometers using average occupancy:

$$PKM_m = VKM_m \times OCC_m \quad \text{(B2)}$$

where *PKM_m* is passenger-kilometers for passenger mode *m*, and *OCC_m* is the average occupancy of mode *m*, in passengers per vehicle. For freight transport, vehicle-kilometers are converted into tonne-kilometers using the average load factor:

$$TKM_m = VKM_m \times LF_m \quad \text{(B3)}$$

where *TKM_m* is tonne-kilometers for freight mode *m* and *LF_m* is the average load factor of freight vehicle category *m*, in tonnes per vehicle.

Fuel shares and fuel-economy values are specified as annual trajectories for each vehicle category and vary by scenario (Table A3). In the Baseline scenario, fuel shares follow recent trends and fuel economy improves at its present rate; in the transition scenarios, the shares of electricity, hydrogen, CNG, LNG, and blended fuels rise over time along category-specific paths, and fuel economy improves faster than in the Baseline. In each year, the fuel shares determine how a category's vehicle-kilometers are allocated across fuels and technologies:

$$VKM_{m,f} = VKM_m \times S_{m,f} \quad \text{(B4)}$$

where *VKM_m,f* is the vehicle-kilometers of mode *m* met by fuel or technology *f* and *S_m,f* is the share of that activity met by fuel *f*, with the shares summing to one across fuels for each mode. Fuels include gasoline, diesel, CNG, LNG, electricity, and hydrogen, with ethanol, biodiesel, and compressed biogas blended into gasoline, diesel, and CNG, respectively. Fuel demand is obtained by dividing fuel-specific vehicle-kilometers by fuel economy:

$$FuelDemand_{m,f} = \frac{VKM_{m,f}}{FE_{m,f}} \quad \text{(B5)}$$

where *FE_m,f* is the fuel economy of mode *m* on fuel *f*, expressed as distance traveled per unit of fuel (kilometers per liter for liquid fuels, per kilogram for gaseous fuels, and per kilowatt-hour for electricity). Fuel demand is the physical quantity of each fuel consumed, expressed in fuel-specific units, and cannot be added directly across fuels. Energy demand converts each fuel's demand to a common energy basis using its energy content *EC_f*, so that fuels can be summed and compared in million barrels of oil equivalent:

$$EnergyDemand_{m,f} = FuelDemand_{m,f} \times EC_f \quad \text{(B6)}$$

Total road-transport energy demand is the sum across modes and fuels:

$$TotalEnergy = \sum_m \sum_f EnergyDemand_{m,f} \quad \text{(B7)}$$

The crude-oil import requirement of road transport reported in Section 4.3 is derived from gasoline and diesel demand in four steps. Gasoline and diesel demand, expressed in million tonnes of oil equivalent, is first converted to product mass:

$$ProductMass_{s,t} = EC_{toe} \times \left(\frac{Diesel_{s,t}}{NCV_{diesel}} + \frac{Gasoline_{s,t}}{NCV_{gasoline}} \right) \quad \text{(B8)}$$

where *ProductMass_s,t* is the combined mass of gasoline and diesel demanded in scenario *s* and year *t*, in million tonnes; *Diesel_s,t* and *Gasoline_s,t* are diesel and gasoline demand in Mtoe; *EC_toe* is the energy content of a tonne of oil equivalent (41.868 GJ); and *NCV_diesel* and *NCV_gasoline* are the net calorific values of diesel and gasoline (43.0 and 44.3 GJ per tonne). Product mass is converted to a crude-oil equivalent using the refinery product yield *Y*, the tonnes of product obtained per tonne of crude oil processed:

$$CrudeEq_{s,t} = \frac{ProductMass_{s,t}}{Y} \quad \text{(B9)}$$

The share of crude-oil supply that is imported in year *t*, *ImpShare_t*, starts from the observed share in the base year *t_0* and rises as domestic crude-oil production declines at the annual rate *g*:

$$ImpShare_t = 1 - \left(1 - ImpShare_0\right) \times (1 + g)^{t - t_0} \quad \text{(B10)}$$

for $t \geq t_0$, with *ImpShare_t* equal to *ImpShare_0* in earlier years. The imported crude-oil requirement, in million tonnes, is the product of the crude-oil equivalent and the import share:

$$CrudeImports_{s,t} = ImpShare_t \times CrudeEq_{s,t} \quad \text{(B11)}$$

It is expressed in million barrels per day using the conversion factor BBL, in barrels per tonne of crude oil:

$$CrudeImportsBD_{s,t} = \frac{CrudeImports_{s,t} \times BBL}{365} \quad \text{(B12)}$$

Cumulative crude-oil imports avoided by scenario s relative to a reference scenario *r* over the projection horizon *t_0* to *T*, in million barrels, are given by:

$$AvoidedImports_{s,r} = BBL \times \sum_{t=t_0}^{T} \left(CrudeImports_{r,t} - CrudeImports_{s,t} \right) \quad \text{(B13)}$$

The corresponding avoided import bill at a crude-oil price *P* per barrel is:

$$AvoidedBill_{s,r} = P \times AvoidedImports_{s,r} \quad \text{(B14)}$$

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Yagyavalk Bhatt is a Fellow in the Transportation and Infrastructure department at KAPSARC, where he leads “The Role of Clean Energy Policies: Trends in India’s Transport Sector,” a project estimating India’s transport energy demand and its potential impact on the crude oil supply chain. His expertise spans energy policy and energy economics, transport policy impact analysis, energy transitions in emerging economies, renewable energy, and cost-benefit analysis across the transport and electricity sectors. His research consistently bridges policy, data, and modeling to turn complex questions, from electric vehicle adoption and freight decarbonization to regional power market integration, into evidence for decision-makers.



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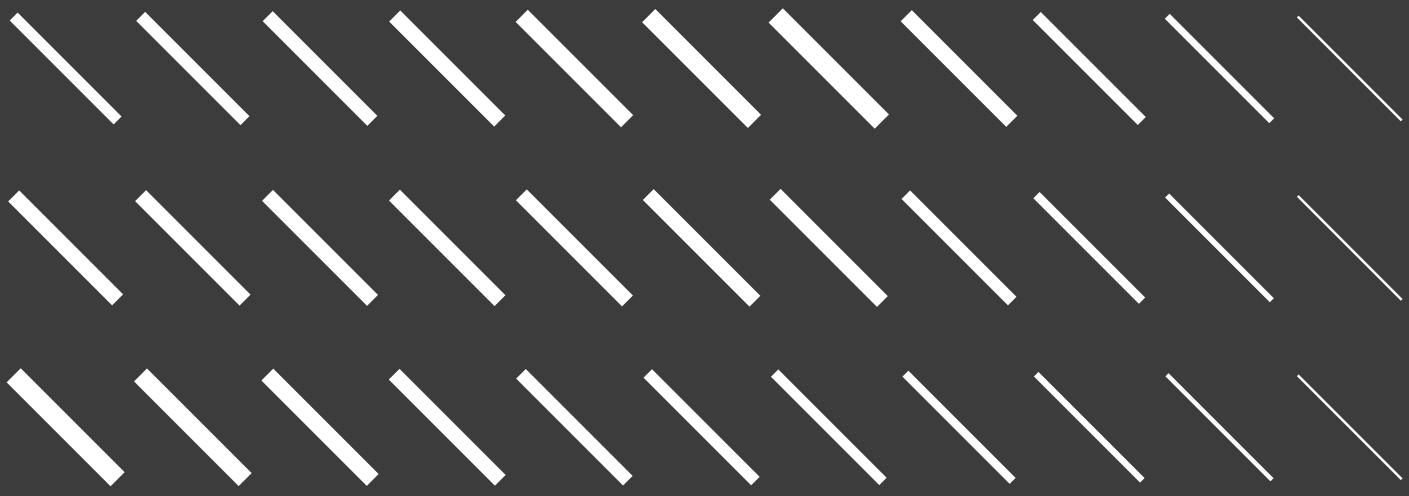
About the Project

This paper was developed jointly by the King Abdullah Petroleum Studies and Research Center (KAPSARC) and The Energy and Resources Institute (TERI), India. It forms part of the KAPSARC project, "The Role of Clean Energy Policies as Part of India's Transportation Sector Decarbonization," which examines how clean energy policies can support transport-sector decarbonization while addressing rising energy demand, fuel transitions, and long-term oil market implications. Focusing on India's road transport sector, the paper assesses future transport energy demand and the resulting crude oil demand under alternative policy and technology scenarios. The analysis provides policymakers, public authorities, and industry stakeholders with insights into how far clean energy policies could reduce India's dependence on crude oil.





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