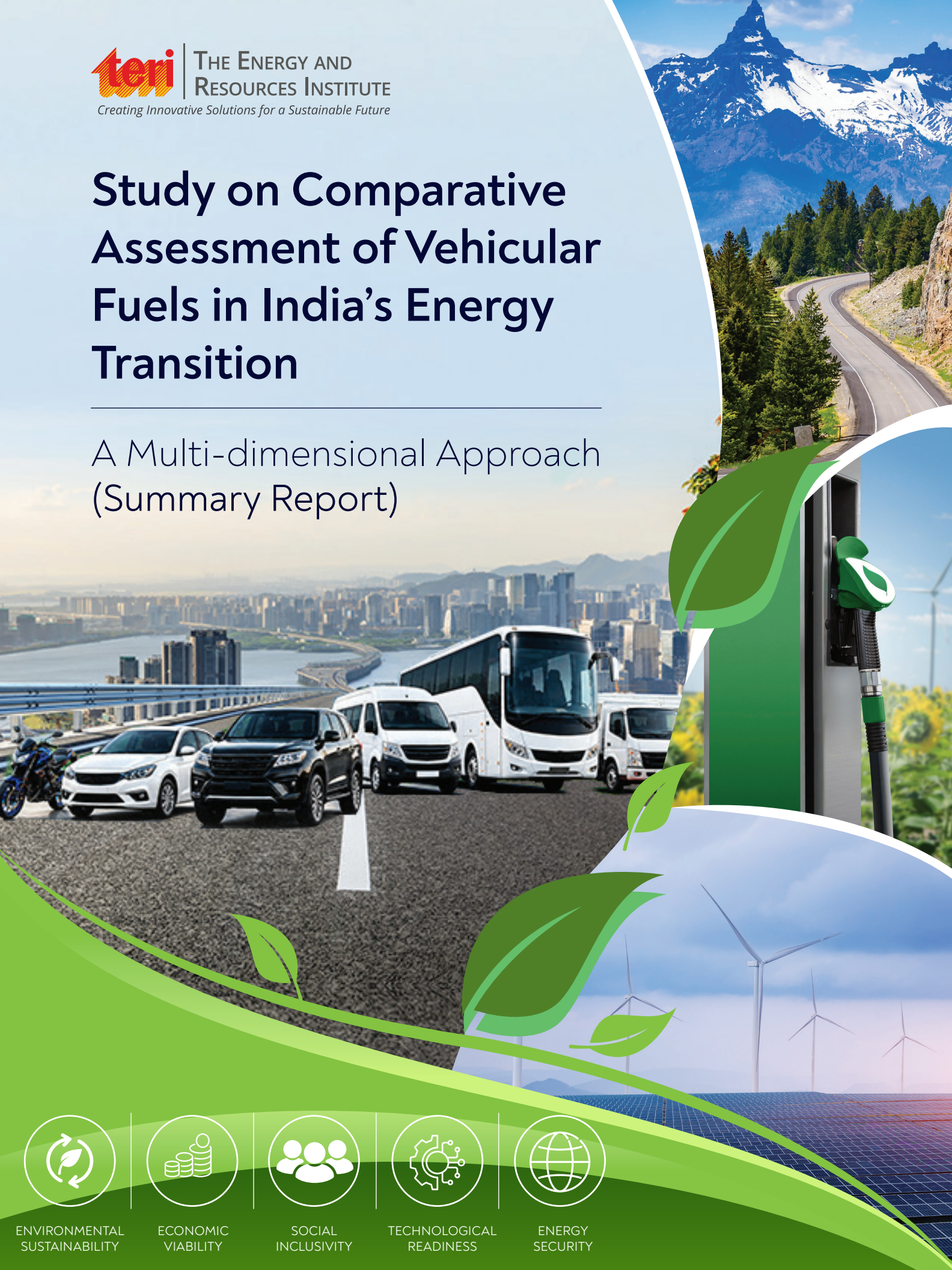


Study on Comparative Assessment of Vehicular Fuels in India's Energy Transition

A Multi-dimensional Approach
(Summary Report)



ENVIRONMENTAL
SUSTAINABILITY



ECONOMIC
VIABILITY



SOCIAL
INCLUSIVITY



TECHNOLOGICAL
READINESS



ENERGY
SECURITY

This report was prepared as part of a study titled 'Study on Comparative Assessment of Vehicular Fuels in India's Energy Transition'.

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Executive Summary

India's road transport sector is undergoing a structural transition driven by multiple national and regional-level goals to reduce carbon emissions, improve urban air quality, strengthen energy security, while maintaining affordable and reliable mobility, enabled by a mix of infrastructure development, policy support, incentivization, etc. The transition, however, is unlikely to be driven by a single fuel or choice of technology. The relative suitability of a fuel or propulsion technology depends on vehicle characteristics, annual utilization of the vehicle, daily travel distance, payload requirements, infrastructure availability, total cost of ownership, environmental impact, technology maturity, and different stages of the transition.

The present study examined the case of five different fuel and technology combinations, namely petrol, diesel, CNG, electricity, and LNG, across six major vehicle segments comprising two-wheelers, three-wheelers, private four-wheelers, commercial four-wheelers, light commercial vehicles, and heavy-duty vehicles. The analysis covered the current scenario along with medium and long-term scenarios for 2030, 2040, and 2050 time horizons. Unlike conventional assessments that focus on a single parameter, this study adopts a multidimensional framework that integrates various parameters across technical, environmental, economic, social, and geopolitical dimensions. These factors were integrated and examined through a multi-criteria decision analysis framework. The scope of the study also consisted of capturing regional variations by incorporating select cities, namely, Delhi, Mumbai, Mumbai Port, Surat, Ahmedabad, Guwahati, Lucknow, Bengaluru, Dhanbad, and Chamba.

Findings of the Study

The central finding of this study is that India should not propose one universal fuel choice as the single winner for replacing all the existing mobility choices; rather, it requires a phased transition in which different technologies perform different roles across vehicle fleets, applications, and stages of transition. The analysis shows that no fuel choice consistently scores highest across all dimensions under the MCDA analysis.

Current Scenario

Petrol and diesel continue to benefit from extensive infrastructure and technological maturity. Currently, CNG offers a relatively balanced and deployment-ready mobility solution across a wide range of applications today across multiple personal and commercial applications owing to low life-cycle cost, lower global warming potential (GWP), and several other parameters analyzed in the study. At the same time, under current market conditions, electric vehicles provide the lowest ownership costs for two-wheelers and three-wheelers owing to their low operating costs and high utilization. However, electric vehicles face challenges in some segments due to inadequate charging infrastructure, vehicle payload, technology maturity, battery-related environmental impacts, and import dependence on vehicle components (rare earth metals) & critical-minerals.

Findings of Survey and Analytical Framework

The study conducted surveys and stakeholder consultations across various regions and cities and incorporated their perspectives to derive the weights to be assigned to the parameters in the MCDA framework. Economic considerations emerge as the strongest overall determinant of technology suitability, further affirming the point

that affordability plays a critical role in the mass-mobility segment. At a combined level, economic considerations receive a weight of 31.49%, followed by environmental considerations at 22.34% and technical considerations at 21.25%. Social and geopolitical considerations account for 13.87% and 11.05%, respectively. The relative weights reflect the importance of vehicle affordability, ownership cost, and operating economics while retaining the environmental, technical, social, and energy-security dimensions required for a comprehensive assessment.

The **economic results** show a strong fleet effect where EVs demonstrate particularly favorable economics in high-utilization 2W and 3W applications, where lower energy and maintenance expenditure can offset higher upfront costs relatively quickly. The economic advantage becomes less pronounced with increasing vehicle size. CNG demonstrates low life-cycle cost for passenger cars, taxis, buses, and heavy-duty trucks, while LNG provides an economically attractive alternative to diesel for long-haul freight operations. In HDVs, the large capital and financing requirements of electric vehicles remain a significant constraint despite lower operating expenditure. These findings further reinforce the importance of adopting a segmented approach to transport decarbonization rather than pursuing uniform technology deployment across vehicle segments. The economic attractiveness of electric mobility is also enhanced by concessional GST, lower operational taxation, and state-level incentives. However, these tax concessions and incentives also involve a trade-off with government tax revenues. Technology-neutral policies supported by evidence-based evaluation are therefore more likely to achieve broader sustainability goals.

Infrastructure remains one of the most immediate constraints on the timing of the transition. When availability, spatial distribution, and service time are considered together, the average infrastructure indicator is highest for diesel, followed by petrol, CNG, and EV charging. In the current scenario, the effective service capacity of EV infrastructure is impacted by the substantially longer time required for charging compared with conventional refuelling. Therefore, the number of charging points does not provide an appropriate measure of in-vehicle service capacity. Infrastructure readiness also varies substantially across the cities analyzed in the study. Delhi has the strongest CNG infrastructure position; however, Bengaluru and Delhi perform relatively strongly for EV infrastructure among the nine assessed locations. Mumbai has a very strong conventional-fuel infrastructure but a lower effective EV and CNG service capacity when spatial accessibility and service time are incorporated. Lucknow, Guwahati, Dhanbad, and Chamba reflect considerably lower effective charging capacity. The findings, therefore, indicate that national transition pathways need to be supported by regionally differentiated implementation strategies.

The **environmental assessment**, comprising sub-indicators such as LCA (life cycle assessment), waste generation, etc., demonstrated the importance of moving beyond tailpipe emissions from an overall sustainability point of view. LCA considered fuel production, electricity generation, vehicle manufacturing, vehicle operation, and end of life from a 'cradle-to-grave' boundary consideration. The environmental footprint covers climate change, particulate matter (PM), human toxicity, freshwater ecotoxicity, water use, fossil resource use, mineral and metal resource use, and photochemical ozone formation. EVs perform favorably when considering operational air pollutants loading, which are present in other fuels; however, their current life-cycle assessment was found sensitive to electricity generation mix (which at present is predominantly coal-dependent) and battery manufacturing. Under the current Indian electricity mix, CNG generally demonstrates the lowest overall environmental burden across most vehicle categories, owing to performance across several of the LCA indicators considered in the analysis. The recently approved GOBARdhan scheme targets to increase the compressed biogas (CBG) production by at least 10 times to more than 5 mmscmd. CBG, being a carbon-negative/neutral fuel, when blended with CNG, would make the fuel cleaner and act as a cornerstone of the circular economy. LNG remains particularly relevant in heavy-duty applications. Diesel-based mobility choices consistently performed inferiorly from both the LCA and air pollution point of view.

The **technical assessment** reinforces the importance of vehicle size. EVs remain relatively competitive in two-wheelers and three-wheelers, where vehicle weight and energy requirements are within manageable limits. In light and heavy commercial vehicles, payload becomes increasingly important as per kg per km running cost economics are crucial and a very sensitive parameter. For example, in the 55-tonne HDV comparison, a representative electric truck has a tare weight of approximately 8.8 tonnes compared with around 7.1 tonnes for an LNG truck, implying approximately 1.7 tonnes of additional unladen mass. At a common gross weight, this additional mass directly reduces the weight available for useful cargo. Charging/refueling time and its location present additional constraints.

The study, hence, demonstrates that no single transport fuel consistently outperforms all others across every vehicle category and evaluation criterion. Additionally, consumers make an informed choice when purchasing a fuel type within a category after considering these factors with specific preference/weightage in mind, which is also elaborated in this study using the MCDA framework. Electric mobility emerges as the preferred option for two-wheelers, three-wheelers, and certain specific urban mobility applications. In contrast, CNG provides the most favorable balance of economics, environmental performance, and operational practicality for passenger cars, taxis, buses, and LCVs at present.

Compressed natural gas retains an important role as a fuel choice within this differentiated transition. CNG remains technically, environmentally, and economically relevant in passenger and commercial applications, owing to existing (spread across 784 districts) and rapidly expanding infrastructure, fast refueling, and operating economics. Stakeholder consultation also emphasizes a continuing preference for natural gas in commercial and public transport applications and identifies LNG as particularly relevant to long-haul freight. Therefore, the study highlights the need for a differentiated approach for various fleet options.

The **geopolitical assessment** shows that electrification changes rather than eliminates external dependencies. Petrol and diesel remain exposed to imported petroleum and international price conditions. CNG and LNG reduce direct petroleum dependence but retain exposure to natural-gas supply chain vulnerabilities. EVs reduce direct dependence on import of crude oil and LNG, but significantly increase dependence on import of battery materials and globally concentrated critical-mineral supply chains for lithium, cobalt, nickel, and graphite. The assessment further indicates that this strategic dependence is expected to remain significant. This highlights that strategic dependence is significant and India needs to manage both energy and material dependencies through diversified sourcing, domestic production/exploration and manufacturing, recycling, and material recovery. A balanced policy framework that supports electrification alongside cleaner gaseous fuels such as CNG and CBG will be critical to building a resilient, low-carbon, and energy-secure transport system.

Future Transition Direction

The composite Closeness Index (calculated using the TOPSIS framework), incorporating the fleet-specific weights of the technical, environmental, economic, social, and geopolitical indicators, ranges from 0 to 1, with higher values representing greater relative closeness to the ideal solution within a particular fleet and time horizon. This provides a relative measure within each fleet type/mode and should not be interpreted as an absolute measure of technology quality.

Table i illustrates the fleet-wise transition pattern suggested by the study's outcome. Two-wheelers show the strongest movement towards electrification, with EVs emerging as the dominant long-term pathway. Three-wheelers show a coexistence pathway in which EV competitiveness strengthens rapidly while CNG remains an

important, economical, and reliable complementary transition option. For four-wheelers, electric vehicles offer operational advantages for urban users with access to charging infrastructure, whereas CNG provides the most favorable economics, overall environmental performance, and affordability for high-mileage users. Private four-wheelers show a more gradual transition, with CNG retaining strong relevance while EVs strengthen over time. The commercial four-wheeler showed a policy-led favorable shift towards electrification, with CNG retaining strong intermediate relevance while EVs strengthen over time. LCVs also show favorable long-term movement towards EV for urban and regional applications. HDVs follow a distinct pathway in which CNG remains important for regional freight, LNG becomes increasingly relevant for suitable long-haul applications, and battery electric remains selective within the conditions assessed. While petrol and diesel are currently favored due to significant infrastructure and user preference, they are expected to phase out subsequently in the overall transition of the road transport ecosystem.

Table i: Fleet-wise transition roles as per the analysis

Vehicle segment	Current position	2030	2040–2050 direction	Overall transition role
Two-wheelers	EV emerging strongly; petrol remains established	EV strengthens rapidly	EV becomes the dominant pathway	EV-led transition
Three-wheelers	CNG and EV are both competitive; conventional ICEV (petrol+diesel) weakens	EV strengthens while CNG complements	EV gains importance, CNG retains a complementary transition role	Coexistence: EV + CNG transition
Private four-wheelers	CNG is more competitive; EV remains constrained by current economics/ infrastructure	CNG remains strong; EV strengthens	EV gains importance while CNG remains relevant	Coexistence: Gradual EV transition with CNG as a strong complementary pathway
Commercial four-wheelers	CNG provides strong current economics; EV remains constrained	CNG and EV are both equally important	EV increasingly preferred; CNG remains significant	Coexistence: EV-led transition with CNG support
LCVs	Conventional fuels retain current operating advantages; CNG and EV are increasingly relevant.	EV strengthens with fleet charging. CNG plays a significant role	EV becomes stronger for urban and regional applications; CNG remains relevant	Coexistence: EV + CNG transition
HDVs	Diesel remains operationally dominant; CNG strong; LNG emerging	CNG remains strong; LNG develops	CNG remains relevant for regional freight, LNG strengthens for long-haul applications; EV remains selective	LNG/CNG-led transition with selective zero-emission applications

The overall policy implication is therefore to adopt a technology-neutral framework at the system level while remaining differentiated at the regional, fleet, and application level. This would not only encourage innovation but also incentivize consumers and producers to shift towards cleaner mobility alternatives. EVs should be accelerated for operating profiles such as last-mile connectivity, where charging access and economics support them. CNG, which is a proven clean fuel, should continue to expand where it remains economically, environmentally, and technically justified, avoiding premature under-utilization of viable assets. LNG should be developed selectively for long-haul freight corridors and major routes/highways. Accordingly, economic support should focus on the actual adoption barriers of each fleet rather than applying a uniform subsidy structure. Electricity-sector decarbonization, battery circularity, reduction in import dependence for critical vehicle components and fuels (crude oil and LNG), critical-mineral resilience, alternative fuel production (Biofuels such as CBG), and certified retrofitting should progress alongside the vehicle transition.

The proposed policy approach, therefore, is not one of replacing one universal technology with another. It is a sequenced transition in which infrastructure, investment, and policy support evolve with the changing characteristics of each fleet. A diversified, technology-neutral, and evidence-based approach integrating environmental sustainability, economic competitiveness, infrastructure readiness, consumer preferences, resource security, a push towards a self-reliant India, and policy support would provide the most robust pathway for achieving India's climate, air quality, energy security, and sustainable mobility objectives.

The central policy question, therefore, shifts from “which fuel should replace all others?” to “which fuel or propulsion pathway is most suitable for which fleet, under what operating and economic conditions, and at what stage of the transition?”

1. Introduction

India is at a defining stage of its development trajectory, with the ambition of becoming a developed economy by 2047 while achieving Net Zero emissions by 2070. Achieving these objectives simultaneously requires sustained growth in economic activity, infrastructure, employment, and mobility alongside a progressive transformation of the energy and transport systems. India's road transport sector continues to be overwhelmingly dependent on petrol and diesel, which together account for more than 80% of transport-sector energy consumption. Decisions on vehicles, fuels, charging and refueling infrastructure, energy supply chains, and manufacturing capacity can shape the transport and energy system for decades; poorly sequenced investments could result in stranded assets, infrastructure mismatches, or new forms of supply-chain vulnerabilities. A carefully planned multi-dimensional fuel pathway is essential to ensure that decarbonization supports rather than constrains India's broader development objectives. Rising incomes, urbanization, industrialization, and regional connectivity are expected to substantially increase passenger and freight mobility, while India's final energy demand could increase by around 2–2.5 times by 2047, and electricity generation capacity may need to expand several-fold (NITI Aayog 2026a). Unlike developed economies, India must undertake this transition while mobility demand is still expanding, making affordability, equity, and energy security important considerations alongside emissions reduction (NITI Aayog 2026b). NITI Aayog's Scenarios Towards Viksit Bharat and Net Zero – Sectoral Insights: Transport (Vol. 3), February 2026 (NITI Aayog 2026b) recognizes that the transition away from petroleum cannot depend on a single technology and identifies bio-CNG, biofuels, hybrids, electric mobility, and other cleaner technologies as part of India's evolving transport-energy mix. The report also specifically identifies CNG/LNG together with CBG as having a continuing role in freight and transport decarbonization.

Transport is a critical enabler of this development, connecting people to employment and services, linking producers with markets, and facilitating the movement of goods. India's road network has expanded to approximately 6.7 million km, with National Highways increasing from 91,287 km in 2014 to 1,46,145 km in 2023 (MoRTH, 2026), supported by programs such as Bharatmala, Dedicated Freight Corridors, Sagarmala, PM Gati Shakti, and the National Logistics Policy. India's relatively low per-capita mobility of around 4,273 passenger-km, compared with more than 11,000 km in several developed economies, indicates considerable potential for future growth in transport demand. (NITI Aayog 2026b). Transport contributes approximately 4.5% of GVA, while the automobile industry contributes around 7.1% of GDP and nearly half of manufacturing GDP; logistics costs were estimated at 7.97% of GDP in 2023–24 (NITI Aayog 2026b; PIB 2025; Research PRS Legislative 2026). Efficient transport and logistics will therefore remain central to India's competitiveness and development objectives.

Road transport is particularly significant, accounting for approximately 78% of passenger transport demand and 66% of freight tonne-kilometers (NITI Aayog 2025, 2026b). India's registered road vehicle fleet reached approximately 391 million vehicles in March 2025, including nearly 287 million two-wheelers (MoRTH, 2026). The fleet is heterogeneous, with two-wheelers, three-wheelers, passenger cars, buses, LCVs, and heavy-duty vehicles differing substantially in utilization, travel distance, payload, affordability, operating environment, and infrastructure requirements. A short-distance urban two-wheeler, therefore, faces very different technical and economic conditions from a high-utilization bus or long-haul truck. Regional differences in terrain, climate, road conditions, electricity availability, and fuel infrastructure further reinforce the need for fleet- and context-specific assessment rather than treating road transport as a homogeneous sector.

This large and growing road fleet also creates an important energy and emissions challenge. Transport accounts for approximately 10% of India's GHG emissions and 20% of final energy consumption, with road transport representing the dominant share. (Paladugula et al. 2018). The sector consumes around 80% of high-speed diesel and more than 99% of petrol, while petrol consumption increased from approximately 28 Mt in 2018 to nearly 37 Mt in 2023–24 (MOSPI, 2025; TERI, 2024). With crude oil import dependence at approximately 86% in 2023–24, rising transport demand has implications for emissions as well as international oil prices, geopolitical exposure, and energy security. (PPAC 2026). Road transport also contributes significantly to urban air pollution; in Delhi, transport accounted for approximately 39% of $PM_{2.5}$, 19% of PM_{10} , and 81% of NO_x emissions, although contributions vary across locations, pollutants, and seasons (Chetna et al., 2023; TERI & ARAI, 2018; TERI, 2025). Actual vehicle performance is further influenced by vehicle age, operating conditions, congestion, driving behavior, and maintenance.

The decarbonization challenge is consequently more complex than replacing petrol and diesel with a single alternative technology (Malik et al. 2025). Electric mobility can reduce tailpipe emissions and is particularly relevant for several urban applications, but its overall environmental performance depends on the electricity generation mix, vehicle and battery manufacturing, and mineral supply chains (Peshin, Sengupta, and Azevedo 2022). We perform a state-specific life-cycle assessment of greenhouse gases (GHG). India's electricity system remains substantially dependent on fossil fuels, particularly coal, making renewable energy deployment, grid modernization, storage, and system flexibility important complements to transport electrification (BEE 2025). Large-scale EV adoption may also increase electricity demand and create local distribution constraints, requiring investment in charging infrastructure and electricity networks (Fernandez et al. 2024) leading to environmental issues such as global warming. Moving towards the future, projected population growth will cause an increase in energy demand. Without the transition to cleaner energy generation, a high dependency on electricity generation by fossil fuels will emit more harmful gases, worsening the impacts of global warming. Therefore, the energy industry is moving towards cleaner alternatives through renewable energy (RE). At the same time, dependence on imported crude oil can partly shift towards dependence on critical minerals such as lithium, cobalt, nickel, and graphite, as well as the import of vehicle components. This, therefore, may expose the mining supply chain to other geopolitical vulnerabilities, mining supply chain bottlenecks, and heavy geographic concentration, as a few nations dominate mining and processing capacity. Other pathways have their own trade-offs: CNG can reduce petroleum dependence but may increase exposure to imported natural gas, LNG may be relevant for long-distance freight, and biofuels can diversify the fuel mix while facing feedstock and sustainability constraints (Jeswani, Chilvers, and Azapagic 2025; NITI Aayog 2024). Bio-mobility options like CBG could help diversify risk and contribute to long-term energy security.

India currently has multiple fuel options, including electric mobility, natural gas, ethanol, compressed biogas, and biodiesel. Public EV charging infrastructure increased from approximately 1,760 stations in 2021 to more than 39,000 in 2025, while CNG stations increased from around 1,315 in March 2018 to more than 8,600 in March 2026 (ET Auto 2026; Manini 2025). To address persistent urban air pollution, and mounting emissions, India's shift to electric vehicles (EVs). Ethanol blending increased from around 1.5% in 2013–14 to approximately 14.6% in 2023–24, demonstrating the potential for domestically produced renewable fuels to reduce petroleum dependence (PIB 2026). The GOBARdhan National Circular Bioenergy Scheme was approved in 2026 with an outlay of ₹23,731 crore. The scheme provides for assured CBG offtake through CGD entities, pipeline connectivity, capital assistance, and a CBG obligation trajectory of 3% in FY2026–27, 4% in FY2027–28, and 5% from FY2028–29 onwards for the CNG-Transport and PNG-Domestic segments. Accordingly, India's CNG network should be understood not only

in terms of the natural gas it carries today, but as an established gaseous-fuel platform capable of progressively carrying domestically produced CBG/biomethane. These developments indicate that India's transport sector transition is already multi-pronged, with the relative role of each technology likely to vary by vehicle segment and application. It has been found that blending 20 percent CBG with CNG could make the overall CNG fuel carbon neutral on a life cycle basis, strengthening the government's goal of Net Zero by 2070. As India's total prognosticated CBG potential of about 70 MMT is far in excess of total Natural Gas consumed in the country at around 53 MMT, eventually CBG can become increasingly important component of the NG consumed in the country, thereby, reducing and subsequently, making the NG ecosystem carbon neutral, as per stakeholders. Global geopolitics and vulnerabilities of the global energy supply ecosystem have been fully exposed by the ongoing supply disruption. A nation as vast as India, with aspirations to grow into Viksit Bharat by 2047, cannot continue remaining dependent on global energy supply chains alone, and much less, far more restricted EV-enabling supply chains. India's response to this in the Gobardhan Scheme can be transformative in terms of greening the Indian fuel supply ecosystem while positioning the agrarian and rural sectors as an integral part of a greater solution and contributing to the national economy.

International experience reinforces the importance of the national context. Norway's rapid EV adoption, China's integration of vehicle and battery manufacturing, the EU's emphasis on vehicle standards and renewable fuels, Japan and South Korea's investment in hydrogen, and Brazil's ethanol-based mobility system demonstrate different approaches to transport transition. (Gessner and Kolesova 2026; Hira and de Oliveira 2009; IEA 2024; Kwilinski, Lyulyov, and Pimonenko 2024; Zhu et al. 2026). However, these models cannot be directly replicated in the Indian context because of various factors such as income disparity, vehicle ownership, urban form, mobility demand, electricity systems, domestic resources, industrial structure, and affordability (OCED 2025). India's very large two-wheeler fleet, diverse operating conditions, uneven infrastructure, and continuing mobility growth, diverse socio-economic status require a transition framework tailored to domestic circumstances.

The coexistence of multiple fuels and technologies should therefore be assessed in terms of their suitability for particular requirements pertaining to fleet or specific to applications, rather than against a single technology benchmark. Technical performance, environmental impacts, economics, infrastructure availability, user preferences, energy security, and geopolitical risks can each influence technology suitability, and these dimensions may not point towards the same pathway (Vishnuram et al. 2025). A technology may offer environmental advantages while facing cost or infrastructure constraints, while another may provide operational benefits but retain higher emissions or create new supply-chain dependencies. The policy challenge is consequently to determine which technology is appropriate for which vehicle segment and operating context, while recognizing that relative performance will evolve with changes in vehicle costs, fuel prices, infrastructure, electricity generation, technology maturity, and supply chains (Elango et al. 2024).

Existing studies have examined individual aspects of transport fuel choice, including lifecycle emissions, tailpipe emissions, fuel economy, total cost of ownership, infrastructure, technology maturity, import dependence and energy security; however, their conclusions can vary with the indicators, assumptions and relative importance assigned to different dimensions as well as the boundary of LCA assessment. The environmental performance of EVs, for example, depends partly on the electricity mix and lifecycle boundary, while the economic and operational suitability of CNG depends on vehicle utilization, gas availability, and refueling infrastructure. There is therefore a need for a multidimensional assessment that evaluates these dimensions together rather than considering them independently.

The present study addresses this requirement through a comparative assessment of electricity, natural gas (CNG and LNG), petrol, and diesel across different road-transport vehicle categories and five dimensions: technical, environmental, economic, social, and geopolitical. The assessment also captures regional variations across the cities selected across different regions of the country and considers the transition period of up to the year 2050, during which infrastructure, electricity generation, fuel markets, vehicle technologies, and supply chains are expected to evolve significantly. Over this period, the study assesses the relative strengths, limitations, and suitability of alternative pathways across vehicle segments, operating conditions, and regional contexts, while identifying opportunities to improve the performance of individual technologies. The study thereby seeks to provide an evidence-based basis for policy and planning decisions that balance economic viability, environmental sustainability, import dependence, energy security, and the evolving mobility requirements of India. The following sections present the objectives, scope, and methodology adopted for the assessment, followed by the comparative evaluation, key findings, and policy implications, with detailed versions provided in the main report.

2. Research Objectives, Scope, and Methodology

Given the importance of ensuring a smooth and sustainable transition in India's transport sector, this study was undertaken with the following objectives:

- » To identify and define a comprehensive set of indicators and sub-indicators for comparative assessment of alternative vehicular fuel technologies in the Indian road transport sector.
- » To assess the identified fuel technologies across different vehicle segments, selected regions, and specific use cases, and determine their relative performance across individual indicators.
- » To develop a multi-criteria decision framework for evaluating and assessing the fuel technologies by integrating technical, environmental, economic, social, and geopolitical considerations.
- » To examine how the relative suitability and ranking of fuel technologies vary across vehicle segments and the timeframe considered.
- » To identify the key factors influencing the performance of individual fuel technologies and provide recommendations for addressing their identified limitations and improving their suitability for the transport transition.
- » To evaluate the role of each fuel in India's road transport journey at various stages in a holistic and unbiased manner.

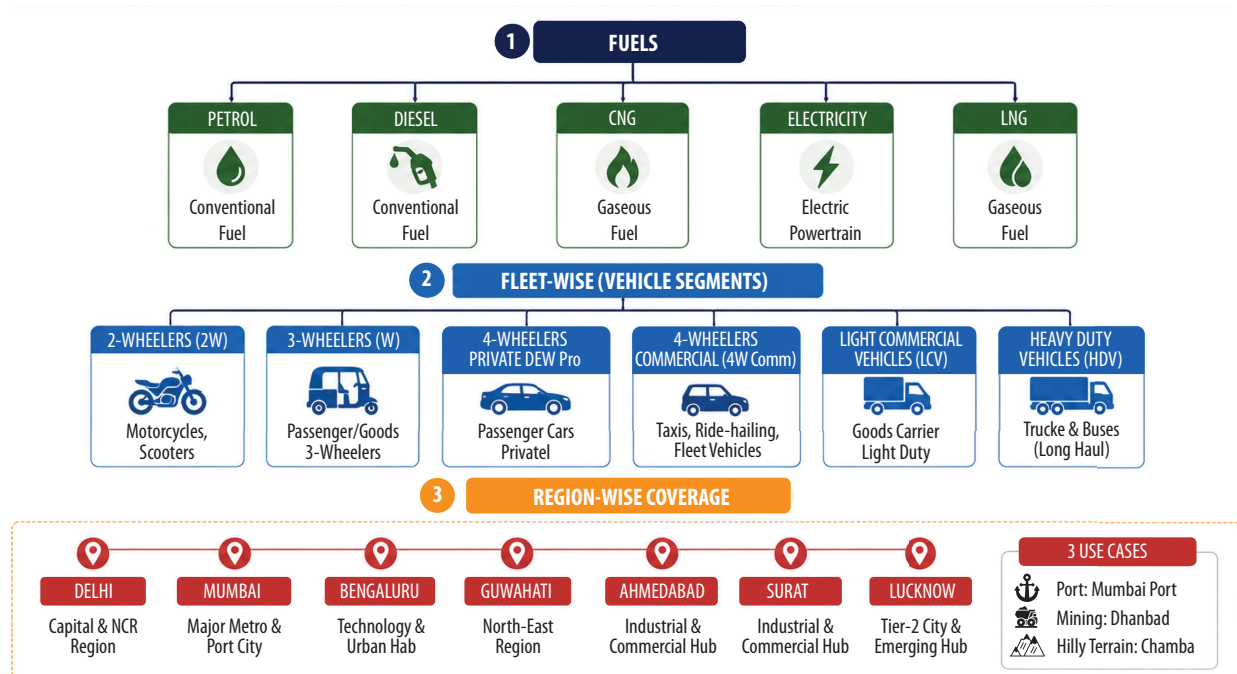


Figure 1: Representation of the scope of the work

- » To attain these objectives, the study adopted a multi-dimensional and fleet-specific approach to assess the performance, sustainability, and role of different fuel alternatives in India's road transport sector over the period up to 2050 (current, 2030, 2040, and 2050). The assessment examined five fuels, namely, petrol, diesel, CNG, electricity, and LNG across six vehicle segments: 2W, 3W, private 4W, commercial 4W, LCV, and HDV. It further captured regional variations across Delhi, Mumbai, Bengaluru, Guwahati, Ahmedabad, Surat, Lucknow, Mumbai Port, Dhanbad, and Chamba (Figure 1).

Each fuel was evaluated against the identified indicators and sub-indicators, and the results were subsequently integrated through a multi-criteria assessment framework to develop comparative scores across vehicle segments and time periods. The five indicators were delineated based on the literature review, relevance to fuel choice and vehicle segments, regional applicability, and data availability. A brief description of the sub-indicators within each of the five indicators is provided in Table 1.

Table 1: Indicators and sub-indicators considered for comparative assessment

Dimension/Indicator	Sub-indicator	Measure used	Preferred direction
Technical	Charging and refueling infrastructure	Infrastructure readiness index	Higher is better
	Kerb weight and payload capacity	Vehicle kerb weight and payload capacity	Lower kerb weight / higher payload is better
	Technological readiness	Technology Readiness Level + stakeholder consultations	Higher is better
Environmental	Life Cycle Assessment	Mid-point lifecycle impact indicators (lifetime score)	Lower is better
	Hazardous material	Assessment score	Lower is better
	Waste generation	Residual mineral waste	Lower is better
	Air pollution	Air pollutant emissions	Lower is better
	Policy implications	Qualitative assessment	Higher is better
Economic	Cost of ownership	Total cost of ownership	Lower is better
	Import burden on the exchequer	Import burden (estimated)	Lower is better
	Subsidies	Subsidy given	Higher is better
	Tax structure	Applicable tax burden	Lower is better
Social	User perspective	Survey-based assessment	Higher is better
	Job creation and the labor market	Stakeholder consultations	Higher is better
Geopolitical	Supply chain vulnerability	Vulnerability assessment score	Lower is better
	Critical minerals consideration	Critical mineral risk score	Lower is better

The indicators and sub-indicators in Table 1 formed the basis of the comparative assessment. Each sub-indicator was evaluated using an appropriate methodology, after which the results were normalized and incorporated into the multi-criteria assessment/TOPSIS framework. While the detailed methodology for the computation of these sub-indicators has been described in the main report, the overall methodology is presented in Figure 2.

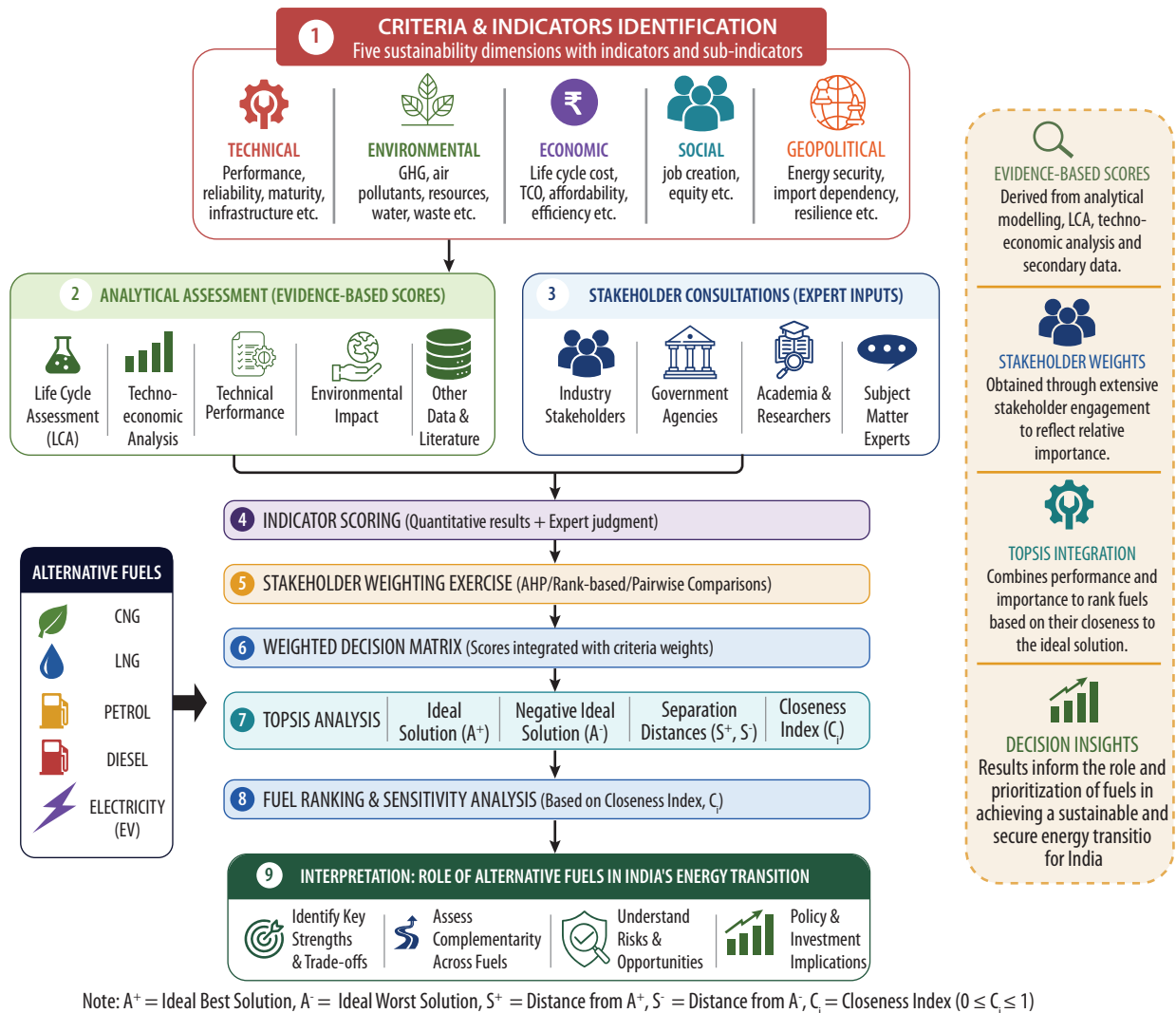


Figure 2: Representation of the overall methodology for the study

A critical component of this study was the structured primary survey of 2,315 vehicle owners and drivers across ten locations, which was conducted using stratified random sampling to capture vehicle characteristics, usage patterns, operating conditions, infrastructure accessibility, fuel and maintenance expenditure, technology preferences, and willingness to retrofit. The locations and sample distribution represented diverse fleet and operating contexts, with vehicle segments and fuel technologies selected in consultation with relevant stakeholders.

The survey provided user-level inputs across multiple indicators, including travel distance, loading, mileage, infrastructure availability, waiting time, fuel/charging expenditure, maintenance costs, technology preferences,

and retrofitting willingness. The findings were used to supplement and, where appropriate, cross-check secondary data and analytical results.

Stakeholder consultations complemented the primary survey by capturing expert and industry perspectives on technology maturity, infrastructure requirements, operational characteristics, technology-specific constraints, and adoption factors across vehicle segments. Inputs from stakeholders across different locations, backgrounds, and organizations were also used to refine and interpret the indicator framework, particularly where quantitative data were limited or practical considerations were important. Further, stakeholder consultation was used to provide weights to the indicators and sub-indicators based on their inputs to live polling and surveys carried out as part of the study.

The assessment compared fuel technologies across sub-indicators with different units and preferred directions (detailed version). To enable aggregation for the MCDA framework, all sub-indicator results were converted to a normalized 1–9 score, with 9 representing relatively better performance. For quantitative sub-indicators, the percentile distribution of alternatives was established using thresholds from the 10th to 80th percentiles at 10% intervals (Eq. 1).

$$P = \{P_{10}, P_{20}, P_{30}, P_{40}, P_{50}, P_{60}, P_{70}, P_{80}\} \quad (1)$$

The number of percentile thresholds equaled or exceeded by each alternative was then determined as shown in Eq. 2.

$$N_i = \sum_{p \in P} 1(x_i \geq p) \quad (2)$$

where N_i represented the number of percentile thresholds exceeded or equaled by the alternative i , x_i represented the observed value of the alternative i , p represented an individual percentile threshold within the set P , and $1(\cdot)$ represented an indicator function that took a value of 1 when x_i was greater than or equal to the corresponding percentile threshold and a value of 0 otherwise. Following this, the number of percentile thresholds crossed was then converted into a score ranging from 1 to 9 using Eq. 3.

$$S_i = \min\{9, 1 + N_i\} \quad (3)$$

where S_i represented the standardized score assigned to the alternative i . The use of the minimum function ensured that the score remained within the defined range of 1 to 9. The percentile-based approach, therefore, provided nine levels of differentiation in the relative performance of the alternatives. The direction of preference was incorporated before scoring so that 9 consistently represented the most favorable and 1 the least favorable performance, irrespective of whether higher or lower values were preferred. For stakeholder-based sub-indicators without continuous numerical distributions, alternatives were directly assessed on the same 1–9 scale. The scores were grouped into three categories for presentation in a consolidated manner as indicated in Table 2.

Table 2: Interpretation and color coding for grouping of scores

Score	Performance category	Colour coding	Interpretation
1 to 3	Low		Relatively less favorable performance
4 to 6	Moderate		Intermediate performance
7 to 9	High		Relatively more favorable performance

The color coding used in fleet-wise assessment matrices represents the underlying assessed score and does not constitute additional weighting. Following standardization, sub-indicator scores were aggregated at the indicator level using their respective weights determined via an expert survey and stakeholder consultation (Delphi-based) (Eq. 4).

$$I_j = \sum_{k=1}^m w_{jk} S_{jk} \quad (4)$$

Where, I_j represented the score of the indicator j , S_{jk} represented the standardized score of the sub-indicator k , w_{jk} represented the weight assigned to the sub-indicator k , and m represented the total number of sub-indicators under the indicator j . Another thing to be noted was that the weights assigned to the sub-indicators under each indicator were normalized such that their sum was equal to one. Thus, the methodology incorporated two distinct levels of weighting. The first level captured the relative importance of sub-indicators within each indicator, while the second level captured the relative importance of the five overarching indicators. The resulting weighted matrix was subsequently used for the TOPSIS analysis to determine the relative ranking of fuel and technology alternatives across the different vehicle categories and assessment contexts.

The weighting framework combined expert assessment and stakeholder preferences to capture both fleet-specific technical and operational considerations and broader stakeholder perspectives. Expert-assessed weights were developed nationally for each vehicle category, reflecting differences in vehicle characteristics, operating conditions, utilization, and transition stage. Stakeholder-derived weights were obtained through structured surveys and live polling in Delhi, Mumbai, Bengaluru, and Guwahati, with approximately 200 responses and inputs. These exercises were vehicle-category agnostic and therefore represented common stakeholder preferences across vehicle categories.

The two sources were combined using a 50:50 allocation, with 50% assigned to fleet-specific expert weights and 50% to stakeholder-derived city-wise weights. Weighting was undertaken at two levels: sub-indicator weights within each of the five dimensions, i.e., technical, environmental, economic, social, and geopolitical, which were normalized to sum to one, and indicator-level weights were similarly normalized.

For stakeholder rankings, a rank-based scoring approach was used. Scores were aggregated and normalized, with adjustments for differences in valid responses where required. The resulting weights were incorporated into the TOPSIS framework, with sub-indicator weights determining contributions within each dimension and indicator-level weights determining the contribution of the five broader dimensions to the overall assessment. This approach combines fleet-specific expert judgment with common stakeholder preferences while retaining differentiation where vehicle characteristics and operating conditions warrant it.

The scores obtained for the individual sub-indicators were aggregated within the five broader indicators, namely technical, environmental, economic, social, and geopolitical, using the sub-indicator weights. The resulting indicator level scores were used as the criteria for the multi-criteria decision analysis. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was applied to assess the fuel and technology alternatives based on their relative distance from an ideal best solution, representing the more favorable performance across the criteria, and an ideal worst solution, representing the less favorable performance. An alternative closer to the ideal best solution and farther from the ideal worst solution was considered more favorable and vice versa. The TOPSIS procedure comprised construction and normalization of the decision matrix, application of indicator level weights, identification of the ideal best and ideal worst solutions, calculation of the separation distances, determination of the relative closeness coefficient, and ranking of the alternatives.

The decision matrix was prepared separately for each vehicle category. The fuel and technology alternatives were represented as rows, while the five broader indicators were represented as columns. The value assigned to each alternative under a particular indicator represented the indicator level score obtained after aggregation of the relevant sub-indicators. The decision matrix was expressed as shown in Eq. 5.

$$X = [x_{ij}] \quad (5)$$

where, x_{ij} represented the score of the alternative i (fuel or technology) for indicator j (technical, environmental, etc). The decision matrix thus provided a common basis for comparing the alternatives across the five dimensions considered in the assessment.

The decision matrix was also normalized using Eq. 6 to bring the scores across the different criteria to a comparable scale.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (6)$$

where, r_{ij} represented the normalized score of the alternative i for j th indicator.

The normalized scores were multiplied by the respective indicator level weights obtained through the stakeholder and expert weighting exercise. The weighted normalized score was calculated using Eq 7.

$$v_{ij} = W_j r_{ij} \quad (7)$$

where, v_{ij} represented the weighted normalized score of the alternative i for j th indicator, r_{ij} represented the normalized score and W_j represented the weight assigned to the indicator j .

The two levels of weighting described were applied sequentially. The sub-indicator weights were used to obtain the score for each broader indicator, while the indicator-level weights were applied at the TOPSIS stage to reflect the relative importance of the five broader dimensions in the overall assessment.

This was followed by identification of the ideal best (more favorable) and ideal worst solutions (less favorable) determined from the weighted normalized decision matrix using Eq. 8-11.

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\} \quad (8)$$

$$v_j^+ = \{ \max_i(v_{ij}) \text{ for benefit criteria; } \min_i(v_{ij}) \text{ for cost criteria} \} \quad (9)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \quad (10)$$

$$v_j^- = \{ \min_i(v_{ij}) \text{ for benefit criteria; } \max_i(v_{ij}) \text{ for cost criteria} \} \quad (11)$$

where, v_j^+ and v_j^- represented the ideal best and ideal worst values for the indicator j . A benefit criterion was one for which a higher value indicated better performance, while a cost criterion was one for which a lower value indicated better performance. Since the scoring framework converted the sub-indicator values such that a higher score represented better performance, the maximum weighted normalized value represented the ideal best, and the minimum value represented the ideal worst for the criteria used in the assessment.

This step was followed by the calculation of the separation index or distance from ideal solutions. Consequently, the distance of each alternative from the ideal best solution was calculated using the Euclidean distance (Eq. 12 and 13).

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad (12)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (13)$$

where, S_i^+ represented the distance of the alternative i from the ideal best solution and S_i^- represented its distance from the ideal worst solution. A lower value of S_i^+ indicates greater proximity to the ideal best solution, while a higher value of S_i^- indicates greater separation from the ideal worst solution.

The final step in TOPSIS is to calculate the relative closeness coefficient using Eq. 14.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (14)$$

where, C_i represented the relative closeness coefficient of the alternative i . The value of C_i ranged from 0 to 1. A higher value indicated better overall performance relative to the other alternatives considered for the particular vehicle category. Since the study emphasizes evaluating the roles of each fuel across fleets, rather than ranking those, the C_i values were used to interpret the potential role of different fuel and technology options across vehicle categories and time horizons. For this purpose, the values were grouped into five categories, as presented in Table 3.

Table 3: Grouping and interpretation of the relative closeness coefficient

Relative closeness coefficient (C_i)	Interpretation	Symbol
$C_i \geq 0.80$	High Strategic Role	●
$0.65 \leq C_i < 0.80$	Significant Role	■
$0.50 \leq C_i < 0.65$	Transition Role	■
$0.30 \leq C_i < 0.50$	Limited Role	◆
$C_i < 0.30$	Marginal Role	■

The categories provided a simplified representation of the TOPSIS results and were used to develop the fuel suitability assessment across vehicle segments and time horizons. The assessment considered the current period and the 2030, 2040, and 2050 time horizons. This enabled the relative role of different fuel and technology options to be assessed not only under the current conditions but also in the context of the expected transition over time.

The TOPSIS analysis was undertaken separately for each vehicle category. The resulting values provided the basis for comparing fuel and technology alternatives within each fleet and for developing the mobility pathways presented in the Results and Discussion section.

3. Results and Discussion

3.1 Weights for Indicators and Sub-Indicators

Sub-indicator-wise results have been presented in the main report, while this version contains the findings of the MCDA framework across fleet and time horizons. The weighting results showed that the relative importance of sub-indicators varied across vehicle fleets, particularly for technical and economic dimensions, where infrastructure, technology maturity, vehicle weight, payload, and ownership cost reflected fleet-specific characteristics. Environmental and geopolitical weights were comparatively consistent, while the social dimension showed limited variation, mainly for private 4W.

At the indicator level, economic considerations received the highest weight (31.49%), followed by environmental (22.34%), technical (21.25%), social (13.87%), and geopolitical (11.05%) considerations, based on the combined stakeholder views and poll/survey results (Figure 3).

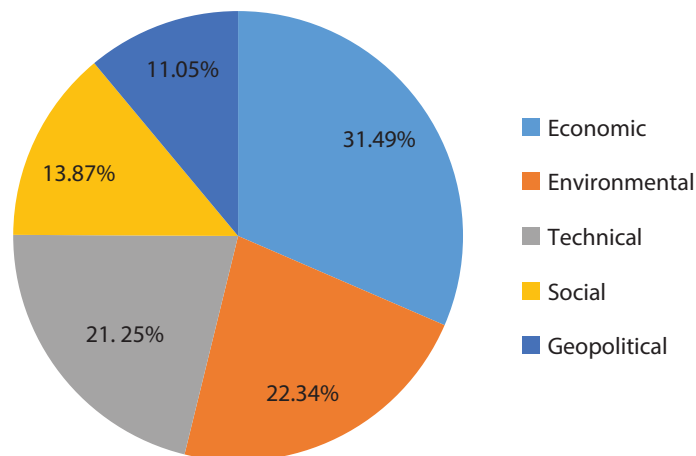


Figure 3: Weights of the indicators considered in the study

Economic performance received the highest importance, reflecting the role of affordability, ownership cost, and operating economics in technology selection. Environmental and technical considerations together accounted for more than two-fifths of the weighting, while social and geopolitical dimensions provided additional differentiation related to user acceptance, employment, energy security, and material supply risks. The broadly stable indicator weights across fleets maintained comparability, with ranking differences arising mainly from technology performance and, subsequently, sub-indicator weights. The technical indicator comprised charging/refueling infrastructure, kerb weight/payload capacity, and technological readiness, with their relative importance varying across vehicle categories (Table 4).

Table 4: Fleet-wise weights for technical sub-indicators

Vehicle category	Charging / Refueling Infrastructure	Kerb Weight / Payload Capacity	Technological Readiness
Two Wheeler	39.56%	22.64%	37.80%
Three Wheeler	37.06%	27.64%	32.80%
Four Wheeler Personal	39.56%	30.14%	32.80%
Four Wheeler Commercial	37.06%	27.64%	32.80%
LCV	32.06%	32.64%	30.30%
HDV/Bus	32.06%	32.64%	35.30%

Infrastructure received relatively high weights across vehicle categories, with the highest importance for two-wheelers and private four-wheelers. In contrast, the importance of kerb weight and payload increased with vehicle size and commercial use, from 22.64% for two wheelers to 32.64% for LCVs and HDVs/buses, reflecting the greater relevance of carrying capacity and vehicle mass in freight applications. Technological readiness was also important for two-wheelers and became particularly significant for HDVs/buses, reaching 35.30%, reflecting the greater technology requirements associated with range, payload, duty cycle, and reliability in heavy-duty applications.

The environmental indicator comprised life cycle assessment, hazardous material, waste generation, air pollution, and policy implications, with identical weights across vehicle categories. Air pollution received the highest weight (32.19%), followed by LCA (26.76%), hazardous material (14.25%), policy implications (15.65%), and waste generation (11.14%) (Figure 4).

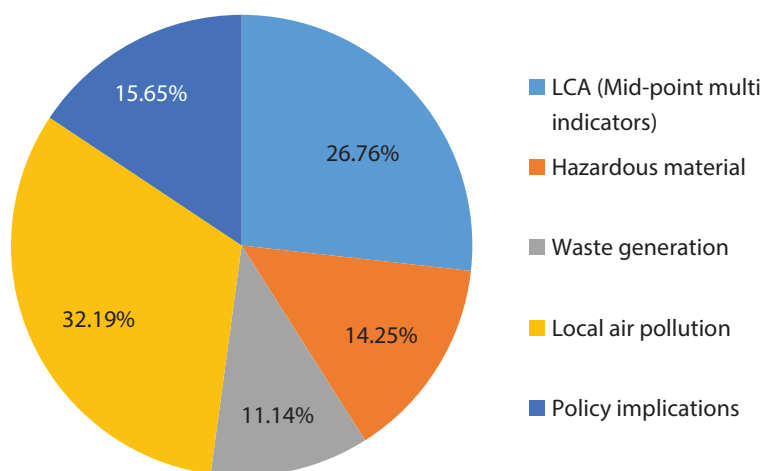


Figure 4: Weights of various environmental sub-indicators

Air pollution received a relatively higher weight due to its importance for local environmental and public-health impacts, while LCA captured broader life-cycle impacts. Hazardous material and waste generation addressed material and end-of-life considerations, and policy implications reflected the influence of the regulatory environment. Constant weighting across fleets provided a consistent basis for environmental comparison, with differences arising from technology-specific performance rather than changing environmental preferences.

In contrast, the economic indicator, comprising cost of ownership, import burden on the exchequer, subsidies, and tax structure, showed variation across fleet types, distinguishing passenger-oriented and commercial applications (Table 5).

Table 5: Weights of various economic sub-indicators

Vehicle category	Cost of Ownership	Import Burden on Exchequer	Subsidies	Tax Structure
Two Wheeler	39.08%	22.91%	15.28%	22.73%
Three Wheeler	39.08%	22.91%	15.28%	22.73%
Four Wheeler Personal	39.08%	22.91%	15.28%	22.73%
Four Wheeler Commercial	44.08%	17.91%	15.28%	22.73%
LCV	44.08%	17.91%	15.28%	22.73%
HDV/Buses	44.08%	17.91%	15.28%	22.73%

Cost of ownership was the dominant economic consideration across all vehicle categories, increasing from 39.08% for 2W, 3W, and private 4W to 44.08% for commercial 4W, LCVs, and HDVs. Conversely, the weight of import burden was 22.91% for the 2-wheeler, 3-wheeler, and private 4-wheeler but decreased to 17.91% for commercial segments, reflecting the greater importance of operating costs and utilization in commercial vehicle technology selection.

The social indicator comprised the user perspective and job creation/labor market implications. User perspective received a larger weight across all categories, at 63.33% versus 36.67% for job creation, except for private 4W, where it received a weightage of 68.33%, and the weight for job creation declined to 31.67%. This reflects the more direct role of consumer preferences in private vehicle choice, while employment considerations remain relevant for commercial and freight applications.

The geopolitical indicator had consistent weights across fleets, with 56.09% assigned to supply chain vulnerability and 43.91% to critical minerals. The higher weight for supply vulnerability reflects the importance of energy security, while the substantial share for critical minerals captures emerging risks associated with battery materials and alternative propulsion technologies. Common weighting across fleets provides a consistent basis for comparison, with differences captured through technology-specific performance scores.

3.2 Fleet-wise Scoring Results

Finally, the following discussion presents fleet-wise results, covering 2W, 3W, private 4W, commercial 4W, LCVs, and HDVs. For each fleet, the analysis considers the five MCDA dimensions and their sub-indicators, followed by the weighted indicator results and their evolution across the 2030, 2040, and 2050 time horizons.

Figure 5 presents the weighted performance of petrol, CNG, and electric two-wheelers across the five MCDA dimensions. The color bands indicate relatively less favorable, intermediate, and relatively more favorable performance. Indicator-level results were derived by aggregating sub-indicator scores using two-wheeler-specific weights.

The technical assessment for **two-wheelers** showed that infrastructure and technological readiness carried the highest weights, while kerb weight/payload had a lower but relevant contribution. Petrol and EV performed favorably on infrastructure, while CNG remained intermediate. Petrol benefited from its extensive refueling network, whereas EVs' favorable position reflected the greater suitability of home charging for two-wheelers rather than equivalent public charging coverage. CNG remained intermediate due to lower accessibility and limited penetration.

Petrol also performed favorably on curb weight/payload and technological readiness, while CNG and EV were intermediate. The additional mass of CNG storage systems and EV batteries affected vehicle characteristics, while EVs' technological readiness reflected substantial commercial deployment. Overall, petrol achieved high technical performance, whereas CNG and EV were intermediate, with EV limited mainly by vehicle weight and CNG by infrastructure reach and technology penetration.

Indicators	Weights (Sub-indicators)	Sub-indicators	Petrol	CNG	EV
Technical		Charging/Refueling infrastructure	Green	Yellow	Green
		Kerb weight/payload capacity	Green	Yellow	Yellow
		Technological readiness	Green	Yellow	Green
Final Tech			Green	Yellow	Yellow
Environmental		LCA (Mid-point multi indicators)	Yellow	Green	Red
		Hazardous material	Green	Green	Yellow
		Waste generation	Green	Green	Yellow
		Air pollution	Red	Yellow	Green
		Policy implications	Green	Red	Green
Final Env			Yellow	Yellow	Yellow
Economic		Cost of ownership	Red	Yellow	Green
		Import burden on exchequer	Red	Yellow	Green
		Subsidies	Red	Yellow	Green
		Tax structure	Yellow	Yellow	Green
Final Eco			Red	Yellow	Green
Social		User perspective	Green	Red	Green
		Job creation + Labor market	Green	Red	Green
Final Soc			Green	Red	Green
Geo-politics		Fuel Supply Chain Vulnerability	Red	Yellow	Green
		Critical minerals consideration	Green	Green	Red
Final Geop			Yellow	Yellow	Yellow

Figure 5: Final comparison matrix for two-wheeler

As per the environmental assessment, CNG performed favorably on LCA, petrol was intermediate, while EV was less favorable under current conditions, with the inclusion of electricity generation and battery manufacturing impacts. Hazardous material and waste generation similarly favored petrol and CNG, while EV remained intermediate due to additional battery-related material management requirements.

EV performed most favorably on air pollution because of zero tailpipe emissions, while CNG was intermediate and petrol was less favorable. Policy implications favored petrol and EV, with CNG intermediate-to-less favorable. Overall, all three pathways were intermediate environmentally, reflecting contrasting strengths: CNG

performed strongly on life-cycle and material aspects, EV on air pollution and policy support, and petrol on mature material and policy systems.

In the economic assessment, CNG and EV performed favorably on ownership cost, while petrol was less favorable. EV also performed favorably on import burden, subsidies, and tax structure, whereas CNG remained intermediate on import burden, and petrol was less favorable. The weighted results placed EV in the high economic category, CNG intermediate, and petrol low, reflecting the combined influence of operating costs, import exposure, and fiscal support.

Petrol and EV performed favorably on both the sub-indicators representing the social dimension, while CNG was less favorable. Petrol benefited from consumer familiarity, widespread availability, and established service networks. EV, on the other hand, benefited from growing adoption and the expanding ecosystem around manufacturing, charging, and servicing. Overall, petrol and EV achieved high weights in social performance, whereas CNG remained low.

Geopolitical assessment concluded that EV performed favorably on fuel supply vulnerability due to lower direct dependence on petroleum, while CNG was intermediate, and petrol was less favorable. Critical mineral considerations, including the rare earth material, on account of imports of components for EV and battery, showed the opposite pattern, favoring petrol and CNG over EV because of their lower dependence on battery minerals. Consequently, all three pathways achieved intermediate scores overall in geopolitical performance, reflecting the trade-off between petroleum dependence and critical-mineral dependence.

The **three-wheeler** assessment showed more favorable results for CNG and EV than for two-wheelers, reflecting the importance of these technologies in commercial and high-utilization applications. CNG performed strongly across multiple dimensions, EV was particularly strong economically and socially, while ICE vehicles retained a technical advantage but performed comparatively weaker environmentally and economically (Figure 6).

ICEV (petrol and diesel) and CNG performed better on infrastructure, while EV remained moderate due to charging constraints in infrastructure. All three performed favorably on kerb weight/payload and technological readiness. Overall, ICEV and CNG achieved high technical performance, while EV remained moderate, mainly due to the current state of infrastructure readiness.

Similar to 2W, CNG performed better on LCA, while ICEV was moderate and EV low under current conditions due to battery manufacturing and electricity-generation impacts. Hazardous material and waste performance favored ICEV and CNG, while EV was moderate. EV performed better on air pollution and policy implications, whereas ICEV was low on air pollution and policy, and CNG remained moderate/low on these sub-indicators. Overall, CNG achieved high environmental performance, EV moderate, and ICEV low.

Cost of ownership carried the highest economic weight. EV performed better on cost of ownership, import burden, subsidies, and tax structure; CNG was moderate on ownership cost and import burden, while ICEV was low on both. The weighted results placed EV in the high economic category, CNG moderate, and ICEV low, reflecting the importance of operating costs for better-utilized three-wheelers with higher utilization.

Within the social category, CNG and EV performed better from the user perspective, while ICEV was moderate. Job creation favored ICEV and CNG, with EV remaining moderate due to its less mature ecosystem. Overall, CNG and EV achieved high social performance, while other ICEVs remained moderate.

EV performed better on fuel supply chain vulnerability, CNG moderately, and ICEV low, reflecting their differing dependence on petroleum and natural gas imports. Critical mineral considerations showed the reverse pattern,

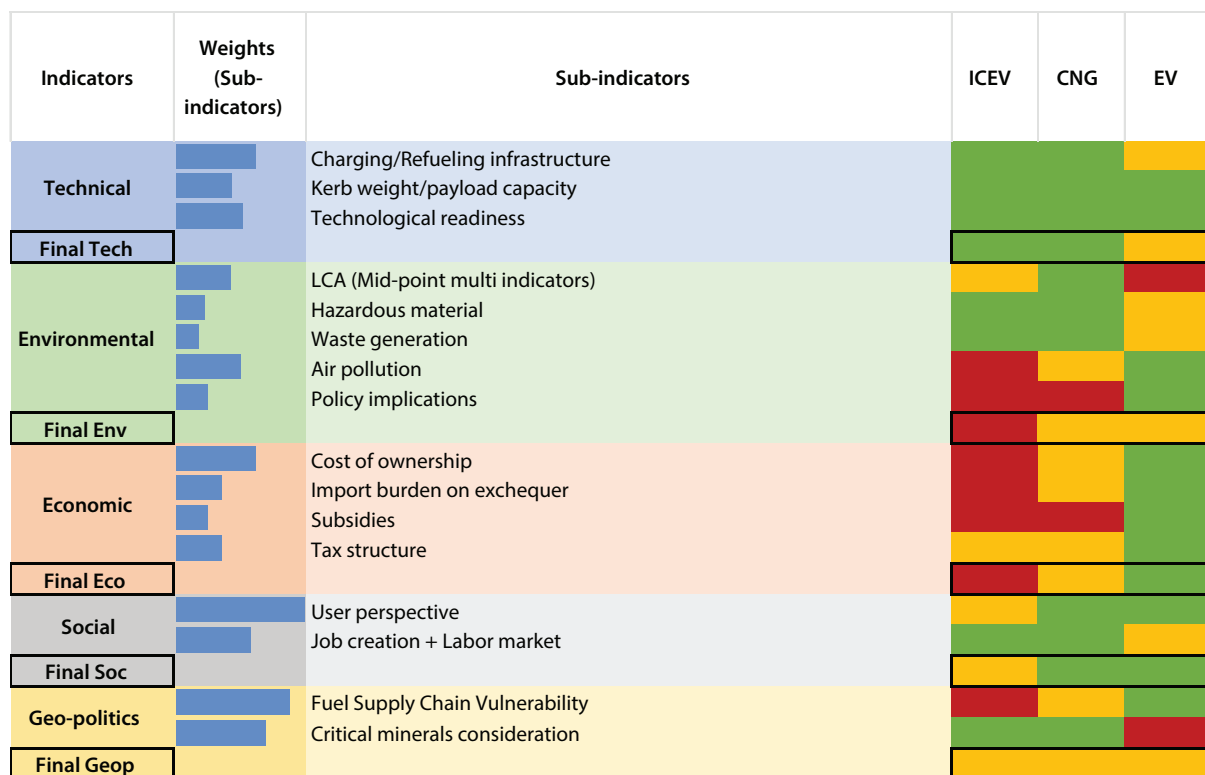


Figure 6: Final comparison matrix for the three-wheeler fleet

with ICEV and CNG high and EV low. The weighted results placed all three pathways in the moderate geopolitical category, capturing the shift from petroleum dependence towards natural-gas and critical-mineral supply-chain dependence.

The **private four-wheeler** assessment showed a more differentiated competitive position, with petrol and diesel retaining technical strengths, CNG performing relatively consistently across dimensions, and EV gaining advantages in economic and policy aspects. However, under current conditions, EV advantages did not fully offset technical, life-cycle, and material-related considerations as reflected in Figure 7.

Petrol, diesel, and CNG performed better on infrastructure, while EV was moderate due to developing charging networks, charging time, and parking constraints. Petrol, diesel, and CNG also performed better on kerb weight/payload and technological readiness, while EV remained moderate, mainly due to battery weight and infrastructure limitations. Overall, petrol, diesel, and CNG achieved high technical performance, while EV was moderate.

Yet again, CNG performed better on LCA, petrol moderately, and diesel and EV low under current conditions. Petrol and Diesel performed better on hazardous material and waste generation, while EV was moderate/low. EV performed favorably on air pollution and policy implications, whereas petrol and diesel were least favorable on air pollution. Overall, CNG achieved high environmental performance, while petrol and EV were moderate, and diesel was the lowest.

Indicators	Weights (Sub-indicators)	Sub-indicators	Petrol	Diesel	CNG	EV
Technical		Charging/Refueling infrastructure				
		Kerb weight/payload capacity				
		Technological readiness				
Final Tech						
Environmental		LCA (Mid-point multi indicators)				
		Hazardous material				
		Waste generation				
		Air pollution				
		Policy implications				
Final Env						
Economic		Cost of ownership				
		Import burden on exchequer				
		Subsidies				
		Tax structure				
Final Eco						
Social		User perspective				
		Job creation + Labor market				
Final Soc						
Geo-politics		Fuel Supply Chain Vulnerability				
		Critical minerals consideration				
Final Geop						

Figure 7: Final comparison matrix for private four-wheeler fleet

Similarly, CNG performed better with respect to total cost of ownership (TCO), while petrol and EV were moderately to less favorable, and diesel was the lowest. EV performed better on fuel import burden and tax structure. Overall, CNG and EV achieved moderate economic performance, while petrol and diesel were low. The relatively higher upfront cost and lower utilization of private EVs limited the impact of their operating-cost advantage.

Petrol and CNG performed better from a user perspective, while diesel and EV were moderate, reflecting the importance of familiarity, convenience, charging access, range, and vehicle cost. Job creation also favored petrol, diesel, and CNG, while EV remained moderate due to its developing ecosystem. Overall, petrol and CNG achieved high social performance, while diesel and EV were moderate.

EV performed better on fuel supply chain vulnerability, CNG moderately, and petrol and diesel low, reflecting their differing dependence on imported fuels. Critical mineral considerations and import dependence for auto components showed the reverse pattern, favoring petrol, diesel, and CNG over EV. The weighted aggregation placed all four alternatives in the moderate geopolitical category, reflecting different combinations of petroleum, natural-gas, and critical-mineral supply-chain dependence.

The **commercial four-wheeler** assessment highlighted the operational strengths of established ICE technologies, the balanced position of CNG, and the emerging but currently constrained position of EVs. Given the importance of utilization, operating cost, vehicle availability, payload, and predictable operations, petrol, diesel, and CNG performed strongly technically, while EV remained constrained mainly by infrastructure and vehicle characteristics. CNG showed the strongest overall balance across the five dimensions (Figure 8).

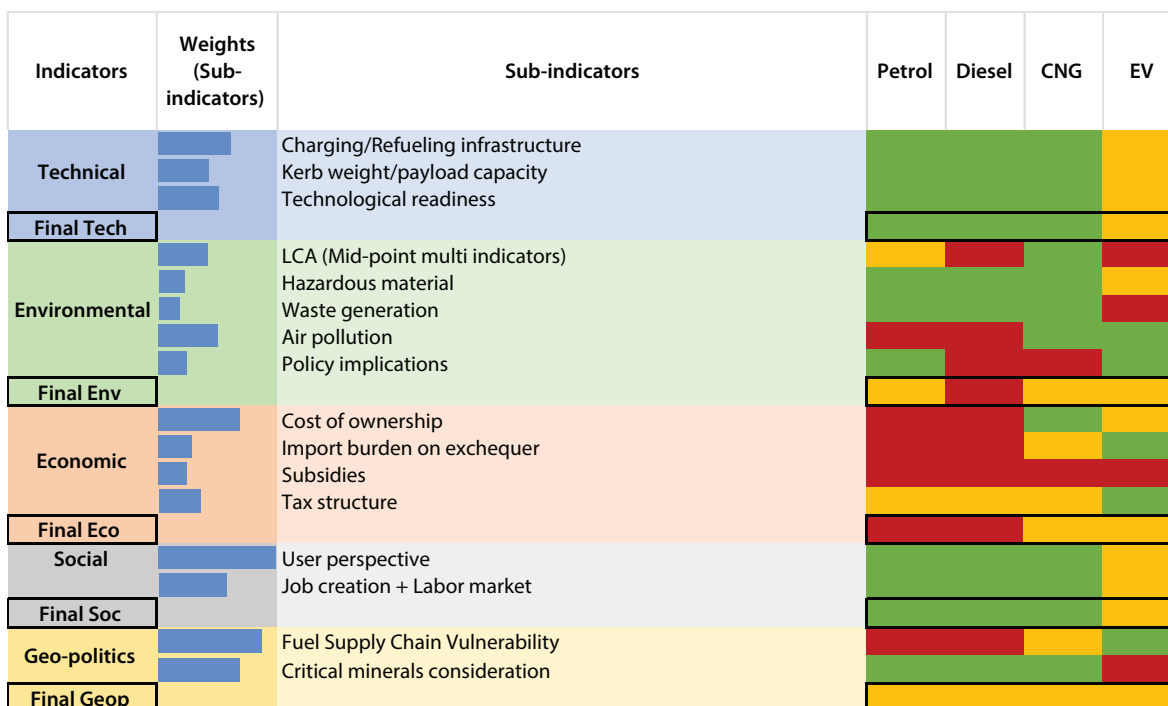


Figure 8: Final comparison matrix for commercial four-wheeler fleet

Petrol, diesel, and CNG performed better on infrastructure and technological readiness, while EV remained low on infrastructure and moderate on the other technical aspects. Overall, petrol, diesel, and CNG achieved high technical performance, while EV remained moderate, primarily due to charging access, downtime, and battery-related weight constraints.

CNG achieved high environmental performance, while petrol and EV were moderate, and diesel was the lowest. CNG benefited from favorable LCA, material, waste, and relatively better air-pollution performance compared to diesel and petrol. EV performed favorably on tailpipe emissions and policy implications but remained constrained by current LCA, hazardous-material, and waste considerations associated with electricity generation and batteries.

CNG also showed high TCO performance, while EV was moderate, and petrol and diesel were the lowest. EV performed better on fuel import burden and tax structure, but its higher acquisition cost limits its overall economic position. The weighted results placed CNG and EV in the moderate Economic category, while petrol and diesel were low.

Petrol, diesel, and CNG performed better from a user perspective and job creation/labor-market considerations, while EV remained moderate. EV's position reflected practical concerns related to charging time, range, vehicle availability, and operational continuity in commercial use. Overall, petrol, diesel, and CNG achieved high social performance, while EV was moderate.

EV performed better on fuel supply chain vulnerability, CNG moderately, and petrol/diesel (low), while critical-mineral considerations showed the reverse pattern. The weighted results placed all the fuel options considered in the moderate category, reflecting different combinations of fuel and critical mineral dependence.

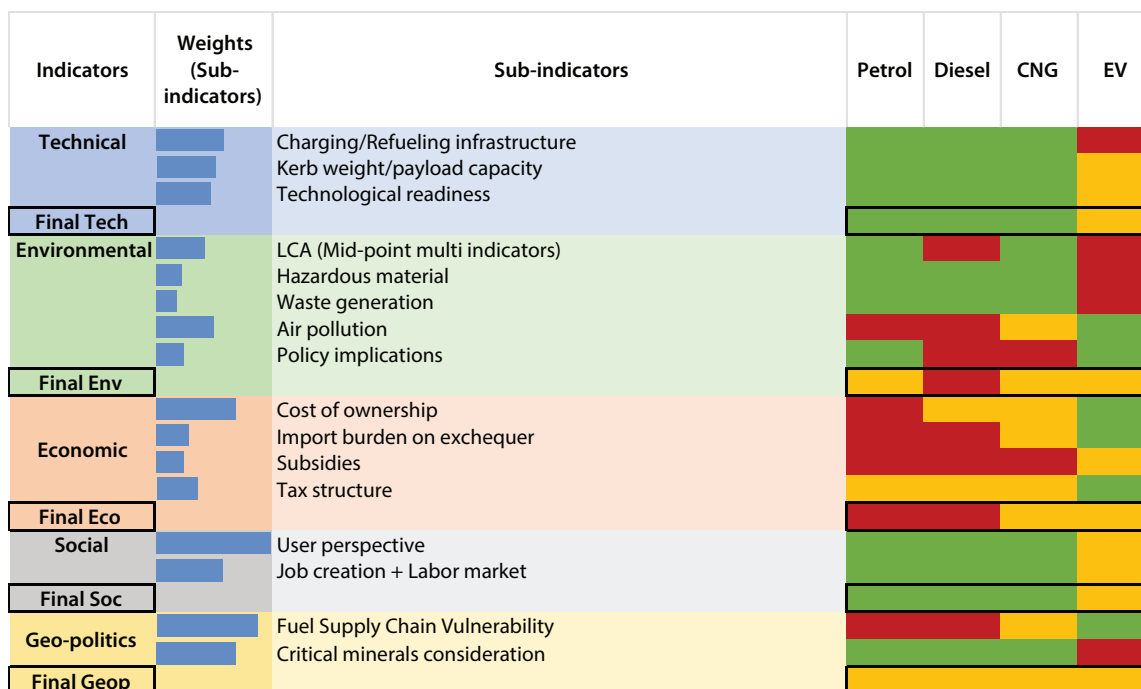


Figure 9: Final comparison matrix for LCV

The **LCV** assessment represented a transition between passenger and heavier freight applications. Petrol and diesel retained strengths in technical and social performance, while CNG showed relatively balanced performance across dimensions. EV presented a mixed but increasingly competitive profile, with strengths in economics and tailpipe emissions but higher constraints related to charging infrastructure, vehicle weight, life-cycle impacts, and user considerations (Figure 9).

Petrol, diesel, and CNG performed better across the technical sub-indicators, while EV remained low on infrastructure and moderate on payload and readiness. Overall, petrol, diesel, and CNG achieved high technical performance, while EV remained moderate, mainly due to charging constraints and battery-related payload implications.

Petrol, CNG, and EV achieved moderate environmental performance, while diesel was the lowest. CNG benefited from favorable scores for the LCA, hazardous-material, and waste characteristics. EV performed favorably on tailpipe emissions but remains constrained by poor life-cycle emissions (due to the current electricity mix) and material-related impacts.

Petrol, CNG and EV achieved moderate environmental performance, while diesel was low. CNG benefited from favourable LCA, hazardous-material and waste characteristics, but its moderate air-pollution score, particularly considering real-world NO_x emissions, moderated the overall result. While vehicle exhausts inherently involve complex chemical interactions—where nitrogen oxide (NO_x) emissions can contribute to the atmospheric formation of secondary particulate matter—empirical studies mapping the exact real-world conversion rates from clean-burning fuels remain limited, highlighting a critical gap for location-specific, scientifically driven assessments. Further, it has been known from literature that for a region like NCR, the annual contribution of BS-VI CNG vehicles is less than 0.005%, thereby concluding that increasing emission norms are also expected to play an important role in the air pollutant loading. EV performed strongly on air pollution and policy implications but remained constrained by LCA and material-related impacts under current conditions.

EV performed better on the cost of ownership & fuel import burden, while CNG and diesel were moderate and petrol low on TCO. EV also benefited from subsidies and favorable taxation. Overall, EV and CNG were in the moderate-to-high economic range, with EV showing the strongest performance, while petrol and diesel remained low.

Petrol, diesel, and CNG performed better from a user perspective and job creation/labor-market considerations, while EV remained moderate. EV's current position reflected continuing concerns around range, payload, charging downtime, reliability, and infrastructure despite its economic advantages.

EV performed better on fuel supply vulnerability, CNG moderately, and petrol/diesel low, while critical-mineral considerations showed the reverse pattern. The weighted results placed all four pathways in the moderate geopolitical category, reflecting different forms of supply-chain dependence across petroleum, natural gas, and critical minerals.

The **HDV** assessment showed the greatest divergence among fuel and propulsion pathways, reflecting the importance of vehicle mass, payload, range, energy replenishment time, utilization, and infrastructure in heavy-duty transport. Diesel retained strengths in technical maturity and user acceptance, CNG showed the most consistently favorable overall profile, LNG offered a strong environmental and long-haul alternative, while EV remained constrained by current technical and economic characteristics (Figure 10).

Indicators	Weights (Sub-indicators)	Sub-indicators	Diesel	CNG	EV	LNG
Technical		Charging/Refueling infrastructure	Green	Yellow	Red	Red
		Kerb weight/payload capacity	Green	Green	Yellow	Green
		Technological readiness	Green	Green	Yellow	Green
Final Tech			Green	Green	Red	Yellow
Environmental		LCA (Mid-point multi indicators)	Red	Green	Red	Green
		Hazardous material	Green	Green	Red	Green
		Waste generation	Green	Green	Red	Green
		Air pollution	Red	Green	Green	Green
		Policy implications	Red	Green	Green	Red
Final Env			Red	Yellow	Yellow	Green
Economic		Cost of ownership	Red	Green	Red	Yellow
		Import burden on exchequer	Red	Green	Green	Yellow
		Subsidies	Red	Green	Green	Yellow
		Tax structure	Yellow	Green	Green	Yellow
Final Eco			Red	Yellow	Red	Yellow
Social		User perspective	Green	Green	Red	Yellow
		Job creation + Labor market	Green	Green	Yellow	Green
Final Soc			Green	Green	Yellow	Yellow
Geo-politics		Fuel Supply Chain Vulnerability	Red	Yellow	Green	Red
		Critical minerals consideration	Green	Green	Red	Green
Final Geop			Yellow	Yellow	Yellow	Yellow

Figure 10: Final comparison matrix for commercial Heavy-Duty Vehicle

Diesel and CNG achieved high technical performance, LNG was moderate, and EV was low. Diesel benefited from extensive refueling infrastructure, while CNG combined adequate infrastructure, payload characteristics, and technology maturity. LNG remained constrained by limited infrastructure and market maturity, while EV faced constraints from charging infrastructure, battery weight, and limited HDV deployment.

CNG and LNG performed better in terms of LCA, while EV and diesel were assessed as low under current conditions. Diesel, CNG, and LNG also performed better on hazardous material and waste, whereas EV performed poorly. EV, CNG, and LNG performed better on air pollution, while diesel was low. Overall, LNG achieved high environmental performance, CNG moderate-to-high, EV moderate, and diesel low, reflecting the trade-off between EV's operational emissions advantage and its current life-cycle and material impacts.

CNG achieved high performance on the cost of ownership, LNG was moderate, and diesel and EV were low. EV performed better on fuel import burden, subsidies, and taxation, but its higher acquisition and financing costs constrained the overall result. The weighted aggregation placed CNG in the high economic category, LNG and EV moderate, and diesel lowest.

Diesel and CNG performed better on the user perspective and job creation, LNG was moderate overall, and EV was low on the user perspective and moderate on employment. EVs' lower social position reflected concerns around range, charging time, availability, and operational reliability in heavy-duty applications. Overall, diesel and CNG achieved high social performance, while LNG and EV were moderate.

EV performed better on fuel supply chain vulnerability, CNG moderately, and diesel/LNG low, while critical-mineral considerations showed the reverse pattern. The weighted geopolitical indicator placed all four pathways in the moderate category, reflecting the shift between petroleum dependence and critical-mineral dependence associated with electrification.

3.3 Comparative Assessment across Fleets till 2050

After arriving at the final comparison matrices across each of the vehicle fleets as described above, eventually, the technical, environmental, economic, social, and geopolitical results were integrated using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to derive a closeness index. Sub-indicators were first aggregated into the five indicators using fleet-specific weights, followed by TOPSIS using the corresponding major-indicator weights. The index reflects each alternative's relative distance from the ideal best and worst solutions.

The closeness index ranges from 0 to 1, with higher values indicating closer proximity to the ideal solution. It is a relative measure applicable only within the same fleet and assessment horizon and should not be interpreted as an absolute technology rating. For interpretation, values of 0.00–0.20, 0.20–0.40, 0.40–0.60, 0.60–0.80, and 0.80–1.00 represent Marginal, Limited, Transition, Significant, and High Strategic Roles, respectively.

The closeness index was calculated for the current assessment and 2030, 2040, and 2050. Future assessments retained the same MCDA structure while allowing relevant sub-indicators, particularly infrastructure, technology readiness, LCA, hazardous material and waste, and critical mineral dependence, to evolve with transition conditions. Accordingly, the resulting trajectories represent indicative mobility transition pathways rather than market-share forecasts.

The closeness index, therefore, provides an integrated measure of the balance between strengths and constraints across dimensions. A high value does not imply superiority across every individual indicator, while

a lower value may reflect constraints in better weighted dimensions despite strong performance elsewhere. The results consequently examine the relative position of each pathway within a fleet, its evolution through 2030–2050, and the potential role it could play in India’s broader transport transition pathway.

The two-wheeler results indicated a clear shift towards electric propulsion over the assessment horizon. Petrol moved from an intermediate current position towards a lower relative position, while CNG remained intermediate. EV progressed from a favorable current position to the strongest long-term position (Table 6).

Table 6: Transition pathway for two-wheeler

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
2 Wheeler	Petrol	■	◆	◆	◆	Declining conventional fuel
	CNG	◆	◆	◆	◆	Niche transition fuel
	EV	■	■	●	●	Dominant long-term fuel

Petrol’s current position was driven by strong technical and social performance, supported by extensive refueling infrastructure, high technological readiness, and user acceptance. However, these advantages were increasingly offset by weaker economic and environmental performance, particularly relative to EVs. CNG remained in an intermediate position across the assessment horizon. Its environmental and supply-chain strengths supported its continued relevance, while limited two-wheeler penetration, infrastructure availability, and user acceptance constrained further improvement.

EV showed the strongest improvement, supported by favorable economic and social performance. Increasing charging availability and technological maturity progressively reduced its current constraints, while improvements in the electricity mix strengthened its life-cycle environmental performance. The resulting convergence of economic competitiveness, technology readiness, charging access, policy support, and environmental performance led EV towards the strongest long-term position. Overall, the two-wheeler results indicate a clear shift towards EV, with petrol moving towards a declining conventional role and CNG retaining a more limited transition role.

The three-wheeler results indicated a shift from a CNG-dominant current position towards EV dominance over time. ICEV remained lowest throughout, CNG moved towards a more limited transition role, while EV strengthened progressively to become the dominant long-term pathway (Table 7).

Table 7: Transition pathway for three-wheeler

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
3 Wheeler	ICEV	■	■	■	■	Phase-out fuel
	CNG	■	■	■	◆	Transition fuel
	EV	■	●	●	●	Dominant technology

ICEV remained in the weakest position, as its high technical maturity and infrastructure availability were outweighed by weak economic and environmental performance. With economic considerations carrying the highest major-indicator weight, its technical advantage was insufficient to offset these disadvantages.

CNG started from a strong position, supported by high technical readiness, established infrastructure, favorable environmental performance, social acceptance, and relatively favorable geopolitical characteristics. However, its relative advantage narrowed as EV infrastructure, technology readiness, and life-cycle performance improved. CNG, therefore, retained relevance as a transition technology but declined in relative position.

EV strengthened primarily through its economic and social advantages, supported by improving technical and environmental performance. The high utilization of three-wheelers further enhances the importance of lower energy and maintenance costs. Overall, the results indicate a shift from CNG as the stronger current option towards EV as the dominant long-term technology, with CNG retaining a transition role as EV constraints are progressively reduced.

The private four-wheeler results indicated a more gradual transition. Petrol remained intermediate, CNG remained strongly competitive, EV strengthened progressively towards the long term, while diesel remained at the lowest level across all horizons (Table 8).

Table 8: Transition pathway for private four-wheeler

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
4 Wheeler (Private)	Petrol	◆	◆	◆	◆	Declining ICE option
	Diesel	■	■	■	■	Rapid phase-down
	CNG	●	●	●	■	Strong complementary fuel
	EV	■	■	■	■	Growing long-term option

Petrol's current position was supported by strong technical and social performance, including extensive infrastructure, high technological readiness, and user familiarity, but weaker economic and environmental performance limited its future improvement. Diesel remained weaker, as its technical strengths were outweighed by poor environmental and economic performance, leading to further deterioration over time.

CNG remained the strongest balanced pathway across the current and intermediate horizons, supported by technical maturity, infrastructure, environmental performance, user acceptance, and relatively favorable economics. Its position remained strong even as EVs improved, supporting its role as a complementary fuel.

EV progressively strengthened as charging infrastructure, technology readiness, electricity-system performance, and economics improved. Its closeness index increasingly approached and surpassed conventional pathways, although it did not immediately displace CNG. Overall, the private four-wheeler transition is gradual, with CNG remaining competitive even in the long term, along with growing EVs' importance. Affordability, infrastructure, and user preferences remain important alongside technology deployment, particularly for extending EV adoption beyond higher-income consumers.

The commercial four-wheeler results showed a policy-led, favorable shift towards electrification. Petrol and diesel remained at the lowest relative positions, CNG stayed strong, while EV progressed from an intermediate current position to the preferred long-term position (Table 9).

Table 9: Transition pathway for commercial four-wheeler

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
4 Wheeler (Commercial)	Petrol	■	■	■	■	Limited future role
	Diesel	■	■	■	■	Declining option
	CNG	●	●	●	■	Primary transition/ complementary fuel
	EV	■	■	●	●	Long-term preferred option

Petrol's low composite position reflected weak economic and moderate environmental performance despite strong technical and social characteristics, with ownership and operating costs being particularly important in commercial applications. Diesel faced similar constraints, with technical strengths outweighed by poor environmental and economic performance and limited policy support, resulting in a declining position.

CNG remained the strongest current and intermediate pathway, combining established infrastructure, technical readiness, environmental performance, user acceptance, and competitive operating costs. Its advantages were particularly relevant for intensively used commercial vehicles, where charging infrastructure and range could constrain EV adoption.

EV showed a favorable improvement over private four-wheelers, as intensive utilization increased the value of lower energy and maintenance costs. Improvements in charging infrastructure and technology readiness further strengthened its economic and environmental advantages, raising its Ci over time.

Overall, EV emerged as the preferred long-term pathway while CNG retained a strong complementary role. The faster movement towards EV in commercial 4W highlights the importance of vehicle utilization, as lower operating costs become more significant with higher annual travel and usage.

The LCV results showed a strong shift towards electrification. Petrol and diesel moved towards the lowest category, CNG remained consistently strong, while EV progressed from a strong current position to a high long-term position (Table 10).

Table 10: Transition pathway for commercial Light Commercial Vehicle

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
Light Commercial Vehicle (LCV)	Petrol	■	◆	■	■	Declining option
	Diesel	◆	■	■	■	Declining option
	CNG	■	■	■	■	Regional Complementary fuel
	EV	■	■	■	●	Urban & regional long-term option

Petrol declined due to weaker economic and environmental performance despite retaining technical strengths, while diesel showed a more pronounced decline as its technical advantages were outweighed by environmental and economic disadvantages. CNG remained consistently strong, supported by technical maturity, infrastructure, favorable economics, and environmental performance, although its role became increasingly application- and location-specific.

EV progressed from a favorable current position to the strongest long-term position, driven by lower operating costs, improved charging infrastructure, improved LCA performance, and zero tailpipe emissions. Overall, the LCV trajectory highlights a shift from CNG as a regional complementary option towards EV as the longer-term pathway, with EV's economic advantages strengthening as technical constraints are reduced.

The HDV trajectory differed markedly from lighter fleets. Diesel remained viable initially but declined to the lowest category over time, while CNG retained a strong position despite moderating by 2050. LNG strengthened substantially to become a strong long-term option for long-haul transportation, whereas EV remained in the low category throughout (Table 11).

Diesel's current position was supported by technical maturity, infrastructure, and user acceptance, but its weak economic and environmental performance increasingly reduced its composite position. CNG remained strong due to its favorable technical, economic, social, and environmental characteristics, particularly its low ownership cost. Its moderating Ci by 2050 reflected the emergence of competing low-carbon pathways rather than an immediate loss of relevance.

Table 11: Transition pathway for Heavy Duty Vehicle

Vehicle Category	Fuel	Current	2030	2040	2050	Transition Role
Heavy Duty Vehicle	Diesel	◆	◆	■	■	Declining conventional fuel
	CNG	●	●	●	■	Regional freight primary fuel
	EV	■	■	■	■	Limited role (urban/regional applications; hydrogen likely for long-haul beyond study scope)
	LNG	■	■	■	■	Long-haul primary fuel

LNG showed the greatest improvement among non-electric pathways, with its long-range suitability and environmental performance increasingly offsetting current infrastructure and readiness constraints. EV remained constrained by battery requirements, payload penalty, energy demand, charging time, vehicle cost, and material dependence, keeping its Ci low across the assessment horizon.

Overall, the HDV results support a differentiated mobility pathway comprising CNG for regional freight, LNG for long-haul applications, declining diesel use, and a limited current-scope role for EVs, highlighting the need for fleet-specific rather than uniform electrification pathways.

4. Conclusions, Key Takeaways, and Policy Recommendations

India's mobility framework is unlikely to follow a single technology pathway, as the suitability of each fuel and propulsion technology varies with vehicle segment, utilization, infrastructure, economics, and regional conditions. The assessment found no single pathway that consistently performs best across the technical, environmental, economic, social, and geopolitical dimensions. Economic considerations emerged as the strongest overall driver, while infrastructure, technology maturity, user acceptance, policy support, and supply-chain resilience also significantly influenced the relative position of alternatives.

Infrastructure remains a major determinant of transition timing. Petrol and diesel benefit from mature refueling networks, CNG has established infrastructure across India, while EV charging effectiveness depends on coverage, capacity, charging time, and grid readiness. The environmental assessment further demonstrated the importance of life-cycle impacts, with EV performance influenced by electricity generation, battery manufacturing, and material requirements, while CNG and LNG remain relevant in several applications.

The composite closeness index confirmed a differentiated fleet transition. Under current market conditions, electric vehicles provide the lowest ownership costs for scooters, commercial two-wheelers, and three-wheelers owing to their low operating costs and high utilization. Considering the energy mix of India, CNG demonstrates a low life-cycle cost and lower GWP for passenger cars, taxis, buses, LCVs, and HDVs. LNG retains important role in HDVs because of payload, range, refueling time, and technology-maturity constraints.

Key Takeaways from the study have been described below:

- » India's transport mobility pathway should be fleet-specific, as technology suitability varies with vehicle function, utilization, travel distance, payload, infrastructure access, ownership pattern, and regional conditions. EV shows favorable potential in 2W and 3W segments, CNG retains a strong position across several segments, viz., passenger cars, taxis, buses, LCVs, and LNG is particularly relevant for suitable long-haul freight applications.
- » Infrastructure readiness is a key determinant of transition timing. Effective charging and refueling capacity depends not only on station numbers but also on location, capacity, utilization, and service time. Economic competitiveness also varies sharply by fleet, with EV advantages being stronger where utilization is high and vehicle costs are manageable, while higher capital and charging requirements constrain larger vehicles.
- » The life-cycle assessment of several passenger and commercial vehicle segments indicates that CNG-powered vehicles have the lowest overall life-cycle emissions among the fuel options assessed.
- » Life-cycle assessment demonstrates that environmental performance cannot be judged solely through tailpipe emissions. EV performance depends on electricity generation, progress in battery technology with respect to alternative battery chemistries coming into existence, and improvement in circularity in the supply chain, while CNG and LNG continue to show relevance in several applications. CNG also retains an important complementary role because of its infrastructure readiness, environmental benefits, technical maturity, user acceptance, and competitive economics.

- » Private four-wheelers require particular attention to affordability, financing, charging access, and resale value, while HDVs require a differentiated strategy because of range, payload, battery mass, and charging constraints. Electrification also changes rather than eliminates energy-security risks by shifting some dependence from petroleum towards electricity infrastructure, critical minerals, imported automobile components and battery supply chains.
- » Across majority of key indicators, CNG emerges as a suitable fuel in the 4W and Commercial segment, available today, while diesel remains the most polluting fuel option. CNG is highly competitive & provides immediate emission benefits. CNG complemented by EVs (with grid getting cleaner) offers a strong pathway for long-term sustainable mobility
- » The closeness index should therefore be treated as a dynamic assessment and periodically updated as vehicle costs, infrastructure, electricity mix, technology maturity, emissions, and supply-chain conditions evolve.

Several policy recommendations have been identified based on the study as a whole. These recommendations are as follows:

- » Adopt a fleet-specific mobility framework: Adopt a segmented transport pathway, recognizing that different fuels should co-exist and are best suited to different vehicle categories across regions for a self-reliant India. Develop differentiated pathways for 2W, 3W, private 4W, commercial 4W, LCV, and HDV rather than applying a uniform technology pathway.
- » Develop infrastructure around actual fleet duty cycles: Move beyond station-count targets and plan charging based on location, capacity, utilization, charging duration, and grid requirements, including distributed charging for 2W, depot charging for commercial fleets, and corridor-based infrastructure for HDVs.
- » Continue strategic CNG infrastructure development: As CNG performs better on parameters viz. LCA, TCO, etc., CNG infrastructure must be accelerated across India, while creating opportunities for carbon-negative domestically produced CBG with significant potential for a nation such as India.
- » Design economic support around TCO and utilization: Tailor financing, incentives, and operating-cost support to fleet-specific barriers rather than relying primarily on purchase subsidies.
- » Develop the EV secondary market: Establish battery-health certification, transparent warranty, and battery-history information, used-EV financing, residual-value assessment, and appropriate insurance mechanisms.
- » Strengthen certified retrofitment: Develop a regulated retrofit ecosystem covering approved kits, vehicle compatibility, trained retrofitters, inspections, emissions testing, and safety checks.
- » Decarbonize electricity alongside transport electrification: Coordinate EV deployment with renewable generation, grid strengthening, storage, demand management, and suitable charging tariffs, while supporting other cleaner fuels such as CNG-LNG/CBG, biofuels, etc. simultaneously.
- » Strengthen real-world emissions assessment: Incorporate real-world operating performance into environmental regulation, particularly for heavily utilized commercial vehicles. Establish battery circularity and critical-mineral strategies: Develop systems for battery collection, second-life applications, recycling, and material recovery alongside diversified mineral sourcing and domestic manufacturing capabilities.
- » Develop differentiated CNG and LNG strategies: Focus CNG/CBG on segments viz. passenger cars, taxis, buses, and LCVs and LNG for long-haul mobility.

- » Make fleet utilization central to clean-vehicle policy: Differentiate policies for private, high-utilization commercial, fixed-route, regional freight, and long-haul freight vehicles.
- » Integrate regional conditions into implementation: Allow cities and states to sequence implementation according to local infrastructure, CGD networks, EV adoption, and freight-corridor characteristics.
- » Avoid premature stranded infrastructure: Allow viable CNG and other infrastructure to transition in an orderly manner while aligning new investments with expected fleet trajectories and asset utilization.
- » Rationalize the Gas Tax Structure: Include natural gas under the Goods and Services Tax (GST) regime to replace the current fragmented state-level VATs.
- » Undertake periodic holistic evidence-based reassessment: Update the MCDA periodically using observed changes in vehicle costs, utilization, infrastructure, electricity mix, technology deployment, emissions, policy support, resale values, and supply-chain conditions to monitor and re-assess roll-out of policy/ incentives/ disincentive structure/ measures.
- » Maintain a technology-neutral policy framework while allowing market conditions and operational suitability to determine technology adoption. This would not only encourage innovation but also incentivize consumers and producers to shift towards cleaner mobility alternatives like CNG/CBG which is available, accessible, affordable, and environmentally sustainable. Enable the technology best suited to each application while avoiding automatic displacement of pathways that remain technically, economically, or operationally relevant.
- » Geo-strategic considerations arising out of the global energy supply chain disruptions point towards identifying ways to reduce dependence on these fuels and components. Schemes/programs such as ethanol blending, Gobardhan Scheme (CBG) provides ways to simultaneously reduce this dependence while also strengthening the agrarian economy. There can be secondary advantages such as reduction of reliance on LPG by replacing it with blended DPNG which can however be realized only if the NG ecosystem gets support to proliferate.

Conclusions

Overall policy message is that India needs a science-based, technology-neutral “National Fuel Policy” consisting of an “Auto Fuel Policy” and “Other Sectoral Fuel Policy” that evaluates and categorizes fuels on the basis of life-cycle emissions, air-quality impact, energy efficiency, resource availability, and overall sustainability, aligned with the objectives of Viksit Bharat 2047, Net Zero 2070, and energy security/self-reliance objectives. Accordingly, the Auto Fuel Vision & Policy should be comprehensively reviewed and updated to reflect the significant technological, environmental, and energy-sector changes since its last review in 2014. The revised policy should adopt a long-term, technology-neutral, and application-specific approach, providing clear and stable policy direction for CNG, CBG/Bio-CNG/Biogas, LNG, EVs, hybrids, hydrogen, and other emerging technologies, while recognizing the complementary role of different technologies across vehicle segments and transition timelines. Such policy clarity and continuity will be critical for mobilizing investment in fuelling and charging infrastructure and enabling an orderly, cost-effective, and sustainable transition. This report provides a weightage framework for fuels based on their emission profiles to support evidence-based promotion, incentivization, and policy support for cleaner fuels. Accordingly, the proposed policy framework should provide appropriate recognition and incentives to lower-emission fuels, including CNG, LNG, CBG, and other emerging cleaner fuels, based on their measured environmental performance. Such an approach would enable informed fuel choices, promote cleaner fuel adoption, and accelerate India’s transition towards cleaner and more sustainable mobility.

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