ROADMAP FOR INDIA'S ENERGY TRANSITION IN THE TRANSPORT SECTOR

THE ENERGY AND RESOURCES INSTITUTE

Creating Innovative Solutions for a Sustainable Future

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Suggested Citation
The Energy and Resources Institute (TERI). 2024. Roadmap for India's Energy Transition in the Transport Sector. New Delhi, India: TERI.

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Acknowledgements

The project team would like to express its deepest gratitude to Dr. Pankaj Sharma and Mr. Vijay Kansal (the Petroleum Planning and Analysis Cell, Government of India) for their valuable inputs at different phases of the project.

The team thanks the attendees of the stakeholder consultation workshop that was conducted in November 2023, particularly Mr. J Senthil Kumar (Directorate General of Shipping, Government of India), Mr. Deepak Suri (Bureau of Energy Efficiency, Government of India), Dr. Namita Singh, Mr. Aviral Yadav, Mr. Pramod Sharma, and Ms. Priyadarshini Alok for their comments and suggestions on the preliminary results.

The project team thanks the survey agency for effectively collecting data on operational characteristics of road transport vehicles in India.

The team takes this opportunity to thank the editorial team at TERI for their contributions in shaping this report.

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Abbreviations

2W	Two-wheeler
3W-P	Three-wheeler passenger
4W-C&J	Four-wheeler cars and jeeps
4W-T	Four-wheeler taxis
ACC	Advanced chemistry cell
ATF	Aviation turbine fuel
BEE	Bureau of Energy Efficiency
BEV	Battery electric vehicle
BG	Broad gauge
BPKM	Billion passenger km
BRTS	Bus rapid transit system
BS	Bharat Stage
BTKM	Billion tonne km
CAFE	Corporate average fuel economy
CAGR	Compound annual growth rate
CBG	Compressed biogas
CBO	CBG blending obligation
CNG	Compressed natural gas
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSFC	Constant speed fuel consumption
DFC	Dedicated freight corridor
DGCA	Director General of Civil Aviation
DGS	Director General of Shipping
DMRC	Delhi Metro Rail Corporation
DST	Department of Science and Technology
EBP	Ethanol blended petrol
EJ	Exajoule
ESY	Ethanol supply year
EV	Electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicle
FCHEV	Fuel-cell hybrid electric vehicle
GHG	Greenhouse gas
GoI	Government of India
GT	Gross tonnage
GTKM	Gross tonne km
GVA	Gross value added
GVW	Gross vehicle weight
HEFA	Hydro-processed esters and fatty acids
HFCV	Hydrogen fuel-cell vehicle
HSD	Highspeed diesel
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IEA	International Energy Agency
IMO	International Maritime Organization
INR	Indian Rupee
IR	Indian Railways
IWT	Inland water transport
LBG	Liquified biogas
LCV	Light commercial vehicles
LDV	Light duty vehicle
LFP	Lithium-ion phosphate
LGV	Light goods vehicles
LMO	Lithium manganese oxide
LNG	Liquified natural gas
LPG	Liquified petroleum gas
MHDV	Medium and heavy-duty vehicles
MHGV	Medium and heavy goods vehicles
MHI	Ministry of Heavy Industries
MIDC	Modified Indian driving cycle
MMT	Million metric tonne
MoEFCC	Ministry of Environment, Forest, and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoNRE	Ministry of New and Renewable Energy
MoPNG	Ministry of Petroleum and Natural Gas
MoPSW	Ministry of Ports, Shipping, and Waterways
MoR	Ministry of Railways
MoRTH	Ministry of Road Transport and Highways
MoSPI	Ministry of Statistics and Programme Implementation
MSW	Municipal solid waste
Mtoe	Million tonne oil equivalent
MV	Motor vehicle
NCA	Nickel cobalt aluminium
NDC	Nationally determined contributions
NEMMP	National Electric Mobility Mission Plan
NH	National highway
NHAI	National Highway Authority of India
NLP	National Logistic Policy
NMC	Nickel manganese cobalt
NMT	Non-motorized transport
OEM	Original equipment manufacturer
OLS	Ordinary Least Square
OMC	Oil marketing companies
PCS	Public charging station
PIA	Policy in action
PKM	Passenger km
PLI	Production linked investment
PMGSY	Pradhan Mantri Gram Sadak Yojana
POL	Petroleum oil and lubricants
PPAC	Petroleum Planning and Analysis Cell
PT	Public transport
RKM	Route km
SAF	Sustainable aviation fuel
SATAT	Sustainable Alternative Towards Affordable Transportation
SIAM	Society of Indian Automobile Manufacturers
TCO	Total cost of ownership
TERI-TptM	TERI transport model
TJ	Tera-Joule
TKM	Tonne km
TTGS	Transition to green shipping
TTW	Tank-to-wheel
TWh	Terawatt hour
URDPFI	Urban and Regional Development Plans Formulation and Implementation
UT	Union Territory
VKM	Vehicle km
VKT	Vehicle km travelled
WTW	Well-to-wheel

Executive Summary

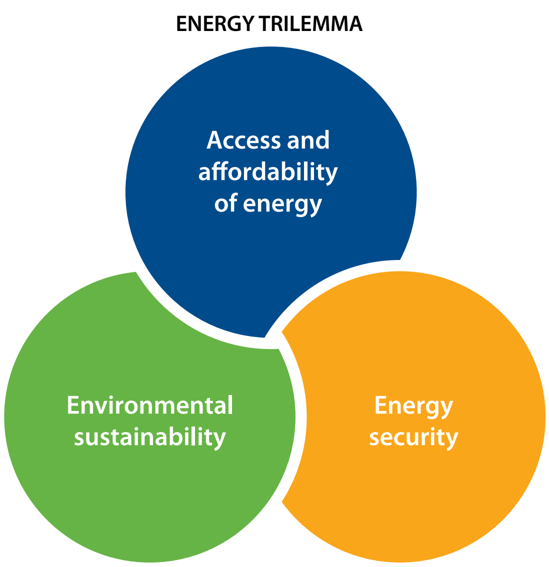
Introduction

Transport sector plays a crucial role in development of a nation, by providing access to public-space, essential services, and opening newer avenues of employment opportunities (direct and indirect). Railways for example have been pivotal in industrial revolution and associated economic prosperity. Despite the existence of fuels like natural gas and new technologies like electric and hybrid vehicles, hydrogen as fuel, the overwhelming contribution of petroleum products to transport sector is undeniable. The alternative fuel technologies have been relatively more expensive for a long time and that has been pivotal to the unprecedented growth of petroleum product demand for transport sector.

Transport sector has been the second highest emitter of carbon dioxide (CO_2), after electricity and heat production sector, contributing almost 23 percent of CO_2 emissions globally and is the fastest growing end-use sector (along with industry). With increasing urbanization in developing countries and expanding needs of the growing population, growth in transport demand is inevitable, and if unchecked, it will have considerable impact on greenhouse gas (GHG) emissions and ambient pollution.

Under the Paris Agreement various countries have committed 'net-zero' targets. To complement the net-zero goals set by different countries, considerable mitigation efforts are put to decarbonise transport sector through multitude of policies– promoting non-motorised transport, active promotion of electric vehicles (EVs), consideration of hydrogen as fuel, biofuel blending with petroleum products, increasing market share of rail, investments in mass-transit, etc.

In this regard, addressing the **energy trilemma** – providing **access to affordable energy** to the citizens; ensuring **energy security** through secured supplies; and providing energy systems that are **environmentally sustainable,** is of particular concern for developing countries due to their limited access to resources, existing inequality in social fabric, and their population pressure. **With the growth and development ambitions of developing countries, like India, it is of paramount importance to strike a balance between the three.** Historically, petroleum products and natural gas have played a pivotal role in meeting the transportation demand of the society. They have been instrumental in providing affordable access to transportation for the citizens. Under the Nationally Determined Contributions (NDC), various countries have adopted mitigation strategies to reduce their GHG emissions from transportation. These strategies include the adoption of alternative fuel technologies, such as electricity and hydrogen as fuels, in transportation that are yet to mature fully compared to the established conventional fuel-based transportation systems. The relatively high cost of these technologies and their future cost dynamics may potentially impact the affordability of transportation, particularly in developing countries.



Need for the Study

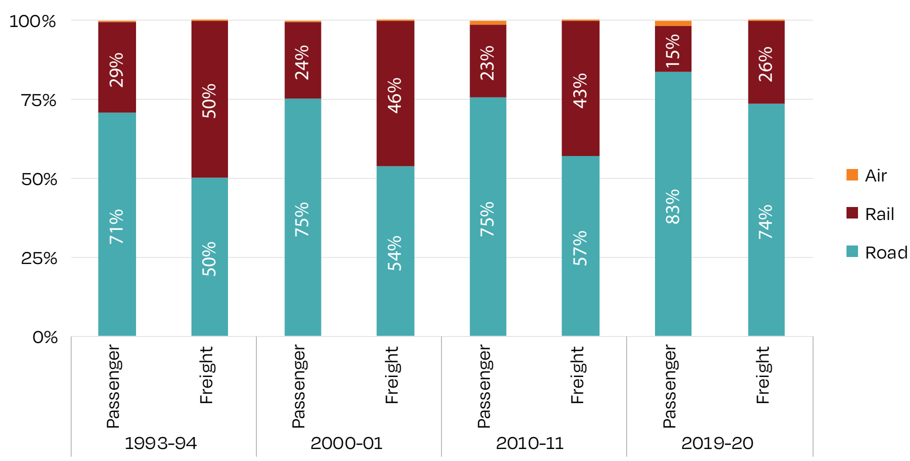
Transport sector in India contributes 5 percent of gross value added (GVA), however, it has a much wider implication for country's development, connecting production centres with the consumption centres, and aiding labour mobility across the country. The share of transport in total CO_2 emission from energy use (IEA, 2023) is 12 percent,[1] much higher than its sectoral share in GVA.

- Between 2000 and 2021, the **share of transport sector in total final consumption of energy has increased considerably from 11 to 16 percent.**
- **Road transport is the backbone of Indian transport system- contributing 83 percent of overall passenger and 74 percent of overall freight traffic in 2019–20.**
- Transport sector accounts for almost **80 percent of highspeed diesel (HSD) and 99 percent of petrol consumption in the country.**

Consumption of HSD and petrol has increased significantly, 2.4 times for HSD and 4.7 times for petrol, between 2003-04 and 2023-24.

- Per capita emission from transport sector was one of the lowest (among the major economies) at **0.282 tonnes of CO_2 equivalent in 2019–20.** However, it is growing at a rapid pace.

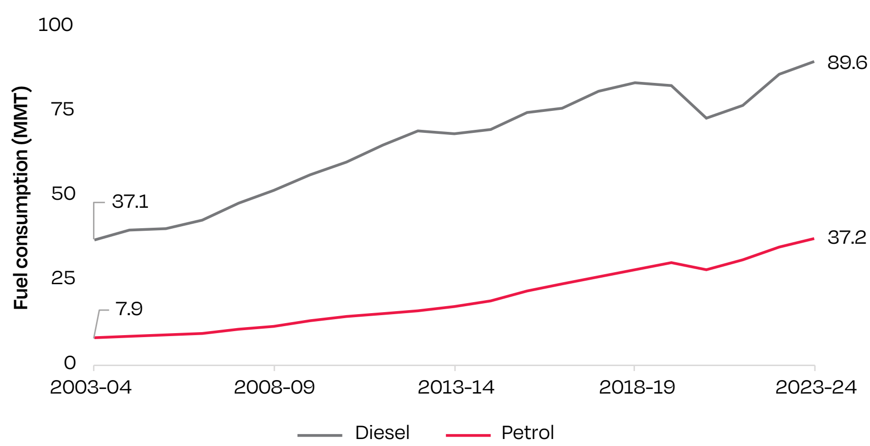
Figure 1: Share of road, rail, aviation in passenger and freight transport demand



Note: The numbers are rounded-off to nearest integers

Source: TERI

Figure 2: Total diesel and petrol consumption



Source: Petroleum Planning and Analysis Cell (PPAC)

[1] IEA. (2023). Transitioning India's road transport sector. France: International Energy Agency (IEA).

Though the emission intensity of India's GDP is continually declining over more than a decade, the emission intensity of transport sector in India has largely remained stagnant and at a higher level than the same for India's GDP. Thus, there is immense potential for the transport sector to contribute to the target set under India's Nationally Determined Contributions (NDC) – to reduce emission intensity of GDP by 45 percent over 2005 level by 2030. Moreover, given the expanding transport demand and criticality of some of the sectors, India's ambition to achieve net-zero emissions by 2070 and address the growing pollution in its cities are also linked to the transport sector of the country.

Objectives

This report focuses on assessing the impact of different low-carbon technology-driven pathways for the transport sector on its fuel demand and GHG emissions. The key objectives are:

- Develop a baseline scenario for the Indian transport sector encompassing different vehicle types across all modes of transport, for assessing fuel demand and GHG emissions
- Analyse different scenarios based on degrees of adoption of alternate fuel technologies, different biofuel blending prospects, and fuel efficiency improvement of vehicles, in terms of their impacts on fuel demand and GHG emission abatement potential
- Deliberate on the challenges associated with the low energy transition in transport sector and understand the policy implications of the alternative scenarios

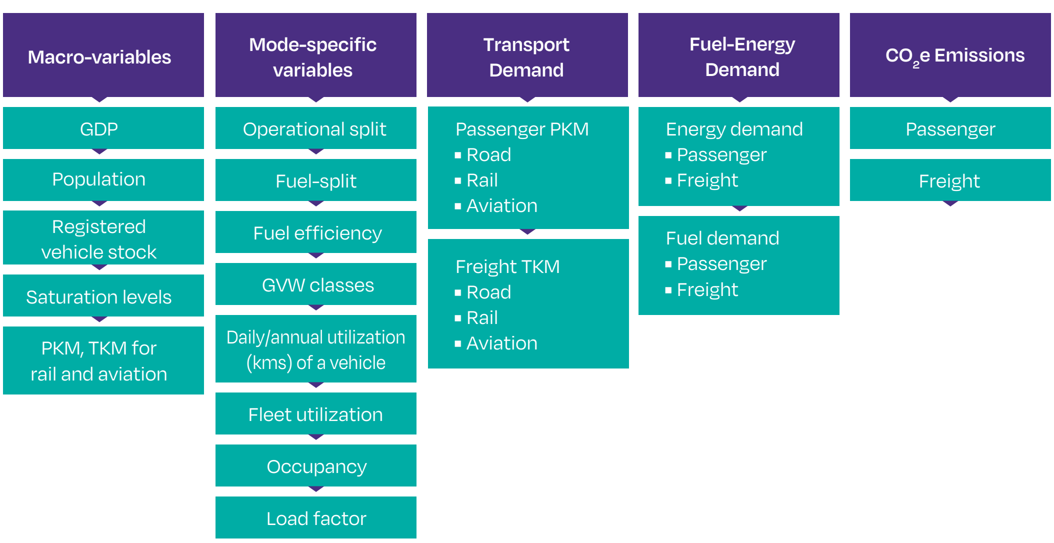
Methodology

This study uses the **TERI Transport Model** (TERI-TptM) which is a **bottom-up approach to estimate domestic transport demand** (passenger and freight). It first estimates the total transport demand, followed by estimations of the energy demand[2] and GHG emissions (measured by CO_2 equivalent emissions).

Model Description

The model is disaggregated by three modes of transport – road, railways, and domestic aviation.

Figure 3: Structure of the TERI Transport Model



Note: PKM- Passenger-km; TKM- Tonne-km; GVW- gross vehicle weight; coastal shipping has not been integrated into the model due to lack of data, however a short-term projection has been included separately.

Source: TERI

[2] Energy demand in this report represents the energy demand from various transportation fuels (petrol, diesel, liquid petroleum gas, aviation turbine fuel, natural gas, electricity, and hydrogen).

As a first step, transport demand is estimated for different modes of transport. Second, based on assumptions on fuel-split and operational characteristics of the road transport vehicles, corresponding energy and fuel demands are estimated. Once the fuel demand is estimated, as the final step, the GHG emissions are estimated based on fuel-specific emission factors.

Scenario Development

As part of the fuel demand and emission estimations, a baseline scenario and three decarbonisation scenarios (alternative scenarios) were developed. The scenarios are primarily technology-driven approaches to reduce GHG emissions from transport sector.

Government of India (GoI) has framed a multitude of policies on **biofuel blending** and identifying sectors for introducing alternative fuel technologies (involving battery electric vehicles and hydrogen fuel) as viable options for transport decarbonisation, along with greater push for natural gas as fuel. Railways with high degree of electrification of the route length and traction is also being considered as a viable mode for substituting road transport, thereby reducing GHG emission footprint. Further, improved technological efficiencies and revised **fuel economy standards** have clear impact on reduction of emission from internal combustion engine (ICE) vehicles and reduced energy requirements for alternative fuel vehicles. India is a party to the **EV30@30 campaign** that envisions a 30 percent EV share in the newly registered vehicles by 2030 and is moving fast with electrification of some of the modes of road transport, particularly three-wheelers.

EV adoption for medium and heavy goods vehicle (MHGV) segment is still very low in India, and apart from promoting electrification of this segment, use of **hydrogen and liquified natural gas** (LNG) are also being explored as alternative fuel options to replace diesel. In this regard the **National Green Hydrogen Mission**, launched in 2023, is worth mentioning. It aims to establish India as a global hub of production, usage, and export of green hydrogen and its derivatives. Presently, the production cost of green hydrogen is significantly higher than that for grey or blue hydrogen. A cost-effective yet cleaner hydrogen can provide India with GHG emission abatement potential at reasonable cost, before the country fully shifts to green hydrogen, when it becomes economically viable.

Government of India is actively promoting production, usage, and export of green hydrogen. However, the adoption path in transport sector is likely to start with low-cost gray hydrogen, to blue hydrogen, and then shift to the green hydrogen, when its cost of production reduces.

India is expected to expand its biofuel blending with petrol, diesel, compressed natural gas (CNG), and aviation turbine fuel (ATF). The updated **National Policy on Biofuels** has set a target of ethanol blending of 20 percent with petrol by 2025 and 5 percent blending of biodiesel with diesel by 2030. Additionally, the **CBG Blending Obligation** of the government targets a **5 percent blending of compressed biogas** (CBG) with CNG by 2028–29, and an indicative target set by the government on **use of sustainable aviation fuel (SAF) envisions a 2 percent SAF blending** by 2028 (initially for international flights).

To assess the effects of different policies on transport sector decarbonisation in India; **three alternative scenarios** were identified in this study–

- Policy-in-action (PIA)
- Ambitious
- Highly Ambitious

Further, under the Ambitious and Highly Ambitious scenarios, two pathways were considered, based on different levels of penetration of natural gas (CNG and LNG). These pathways consider the possibility of the existing price differential between petroleum products (diesel and petrol) and natural gas (for transportation) to wane in future, owing to growing import dependence for natural gas and increasing diversion of natural gas to the industrial sector (mostly ammonia production for fertilizers, and in oil refineries).

Table 1: Overview of scenarios

Scenarios	Fuel Economy Improvement	Fossil Fuels in Grid	EV Adoption	Hydrogen as Fuel (Bus and MHGV)	Blending Target
Baseline	Fixed rate	Fixed at present rate of 72%	Low	Nil	10% ethanol
PIA	Periodic improvement over the baseline	Gradual reduction of fossil fuel share to 0% by 2070-71	Meets 30% target by 2030, increased adoption thereafter	Low adoption	Meets biofuel blending targets by 2030-31 and continues thereafter
Ambitious	Same as in PIA	Same as in PIA	Meets 30% target by 2030, higher adoption thereafter than under PIA	Low adoption but higher than under PIA	Meets bio-fuel targets by 2030-31 and increased adoption wherever feasible
Highly Ambitious	Same as in PIA	Same as in PIA	Meets 30% target by 2030, significantly higher adoption thereafter than under PIA	Moderate adoption	Same as in Ambitious

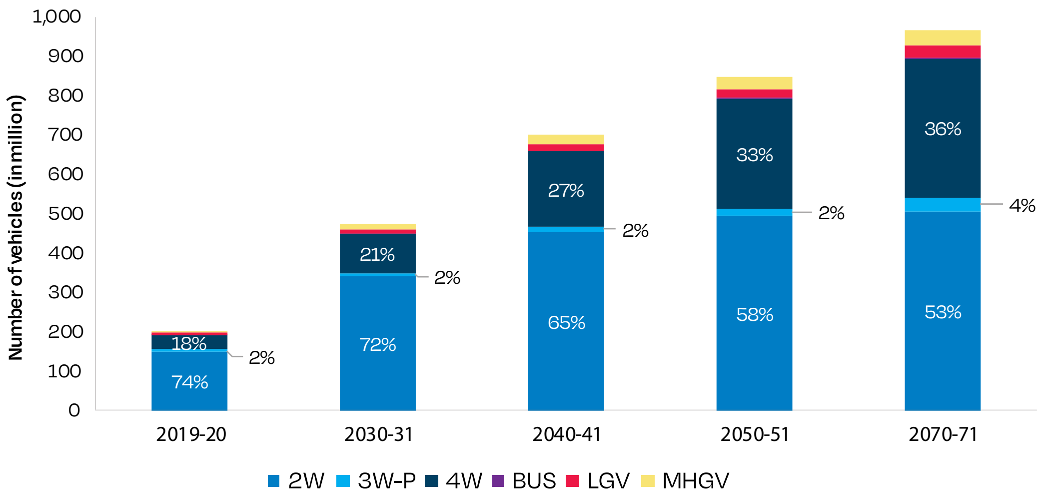
Note: Please refer to Table 6.2 in the main report for detailed assumptions.

Results

Transport demand in the model is derived demand and is kept constant across the four scenarios.

- **Passenger demand** is expected to increase from **7,303 billion passenger km** (BPKM) in 2019–20 to **26,983 in 2050–51,** and **34,284 BPKM by 2070–71,** a more than **four-fold increase** from 2019–20.
- **Freight transport** demand is expected to increase from 2,682 billion tonne km (BTKM) in 2019–20 to 20,644 in 2050–51, and 32,370 BTKM by 2070–71.
- Almost **five-fold increase in estimated number of on-road vehicles** between 2019–20 and 2070–71 (204 million in 2019–20, 474 million in 2030–31, 847 million in 2050–51, and 966 million in 2070–71), however, **the dominance of two-wheelers (2W) will weaken** due to larger adoption of four-wheelers (4W) in India.
- **A shift from modes with less GHG footprint per PKM (2W and Bus) to four-wheelers will be observed,** and by 2070–71 it is expected that the modal share of 4W will be more than the combined modal shares of Bus and 2W (31 percent). MHGV segment will increase its dominance in freight share, from 69 percent in 2019–20 to 89 percent in 2070–71. The share of railways in freight transport will decline from 26 percent to 8 percent during the same period.

Figure 4: Estimated distribution of on-road vehicles



Note: 2W– two-wheelers; 3W-P– denotes three-wheeler passenger vehicles; 4W- denotes four wheeler cars & jeeps, and taxis; LGV– light goods vehicles (gross vehicle weight, GVW ≤ 7.5 tonnes); MHGV– medium and heavy goods vehicles (GVW>7.5 tonnes)

Source: TERI

Figure 5: Projected modal-split in transport

Note: Aviation has negligible contribution to freight transport and is expected to remain the same.

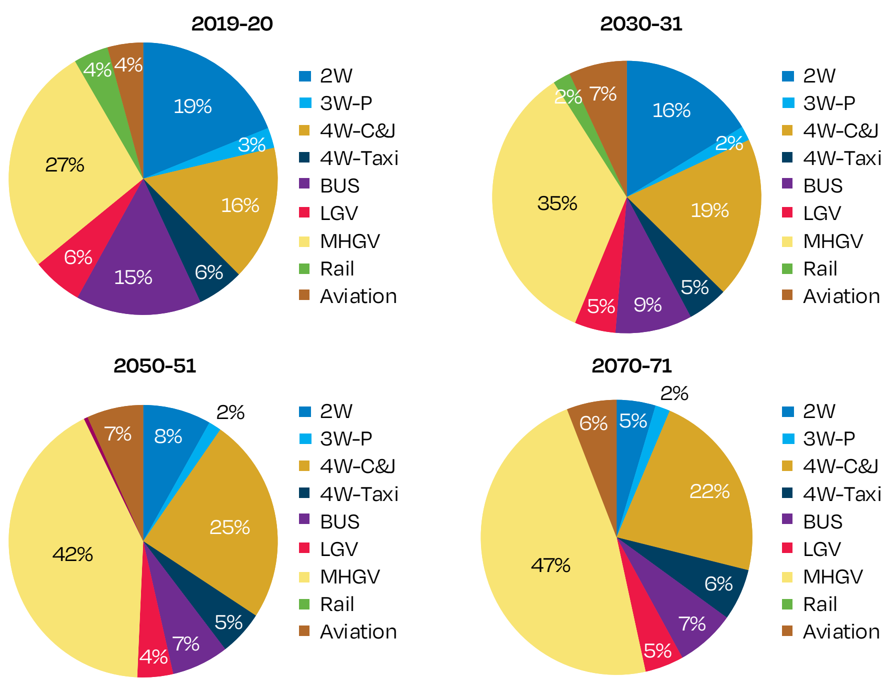
Source: TERI

Baseline Scenario

Under the baseline scenario–

- Energy demand from transport is expected to increase from 5.21 EJ (EJ = Exajoule, 1 EJ = 10^8 Joule) in 2019–20 to 12.27 EJ, 27.59 EJ, and 34.39 EJ in 2030–31, 2050–51, and 2070–71 respectively. **The dominance of passenger transport is expected to decline** from 66 percent of total energy demand in 2019–20 (3.43 EJ) to 50 percent (17.02 EJ) in 2070–71.
- **Energy demand** from fossil fuels will continue to increase; however, the growth will be at a declining rate, particularly for petrol and diesel.
- **Diesel demand** is expected to grow from 65 Mtoe (Mtoe = Million tonne of oil equivalent) in 2019–20 to 146 Mtoe in 2030–31, 337 Mtoe in 2050–51, 411 Mtoe in 2070–71. It is expected to stabilize starting 2060–61.
- **Petrol demand** is expected to expand from 34 Mtoe in 2019–20 to 75 Mtoe in 2030–31, and 133 Mtoe in 2050–51. However, petrol demand is expected to fall starting mid-2050 (a peak demand of 136 Mtoe) and is expected to reach 127 Mtoe by 2070–71.
- **ATF demand** is expected to increase from 4.9 Mtoe in 2019–20 to 18.7 Mtoe in 2030–31, 40 Mtoe in 2050–51, and 42 Mtoe in 2070–71. ATF demand is expected to stabilize starting 2060–61 at 42 Mtoe.
- **Well-to-wheel** (WTW) emissions capture the overall GHG emission impact of the transport sector including the direct (operational/tank-to-wheel) and indirect (well-to-tank) impact of the vehicle use. WTW GHG emission from transport under the baseline scenario is poised to increase more than six times, from 391 million tonnes of CO_2e during 2019–20 to 914 million tonnes of CO_2e by 2030–31, 2,014 million tonnes of CO_2e by 2050–51, and 2,416 million tonnes of CO_2e by 2070–71.
- **Tank-to-wheel** (TTW) GHG emission is expected to grow from 312 million tonnes of CO_2e in 2019-20 to 735, 1,643, and 2,003 million tonnes of CO_2e respectively, in 2030–31, 2050–51, and 2070–71.
- **Road transport will continue to dominate the emission from transport with over 90 percent share.**

Figure 6: Transport sector WTW emission inventory



Source: TERI

Decarbonisation Scenarios

Under the three transport decarbonisation scenarios–

- **Energy demand from transport is expected to decrease under all the three scenarios compared to the baseline,** reaching peak at 28 EJ by 2067–68 under PIA, 25–26 EJ between 2065–67 under the Ambitious, and 22–23 EJ by 2052–54 under the Highly Ambitious scenarios respectively. Energy demand is expected to reach 12 EJ by 2030–31, and range between 22–24 EJ by 2050–51, and 20–26 EJ by 2070–71, under the alternative scenarios.
- In contrast to the projected even split of the energy demand between passenger and freight under the baseline scenario by 2070–71, **the share of passenger transport is expected to fall below 50 percent under the alternative scenarios by end of 2040s** with continued dominance of freight till 2070–71.
- **Petrol demand is expected to peak by 2044–45 at 94 Mtoe under PIA and at 89 Mtoe between 2040–42 under the Ambitious scenario, and 80–81 Mtoe between 2039–41 under the Highly Ambitious scenario.**
- **Diesel demand is expected to peak at 234 Mtoe by 2056–57 under PIA, at 186–207 by 2047–50 under the Ambitious scenario, and at 165–183 Mtoe under the Highly Ambitious scenario between 2043–45.**
- Consequently, demand for natural gas (CNG and LNG) is expected to grow considerably.

Table 2: Projected fuel demand (in Mtoe) in transport sector– Comparison of scenarios

Scenarios	Years	Fuel Demand (Mtoe)								
		Diesel	Petrol	LPG	ATF	CNG	LNG	Electricity	Hydrogen	TOTAL
2020-21		65	34	1	2	4	0	1	0	107
Baseline	2030-31	146	75	1	19	12	1	3	0	256
	2050-51	337	133	0	40	53	9	10	0	582
	2070-71	411	127	0	42	102	28	24	0	734
PIA	2030-31	136	69	0	19	17	1	6	0	249
	2050-51	228	89	0	38	99	23	35	6	518
	2070-71	181	33	0	34	163	65	75	57	608
Ambitious-Pathway 1	2030-31	131	69	0	19	21	4	6	0	250
	2050-51	183	68	0	38	116	48	45	13	511
	2070-71	89	0	0	34	168	130	98	75	593
Highly Ambitious-Pathway 1	2030-31	131	69	0	19	21	4	6	0	250
	2050-51	151	56	0	38	114	52	52	28	490
	2070-71	15	0	0	34	70	87	136	127	468
Ambitious-Pathway 2	2030-31	133	69	0	19	20	2	6	0	249
	2050-51	207	79	0	38	91	23	45	13	496
	2070-71	150	30	0	34	113	50	98	75	550
Highly Ambitious-Pathway 2	2030-31	132	69	0	19	21	2	6	0	249
	2050-51	173	67	0	38	90	29	52	28	476
	2070-71	35	19	0	34	42	57	136	127	450

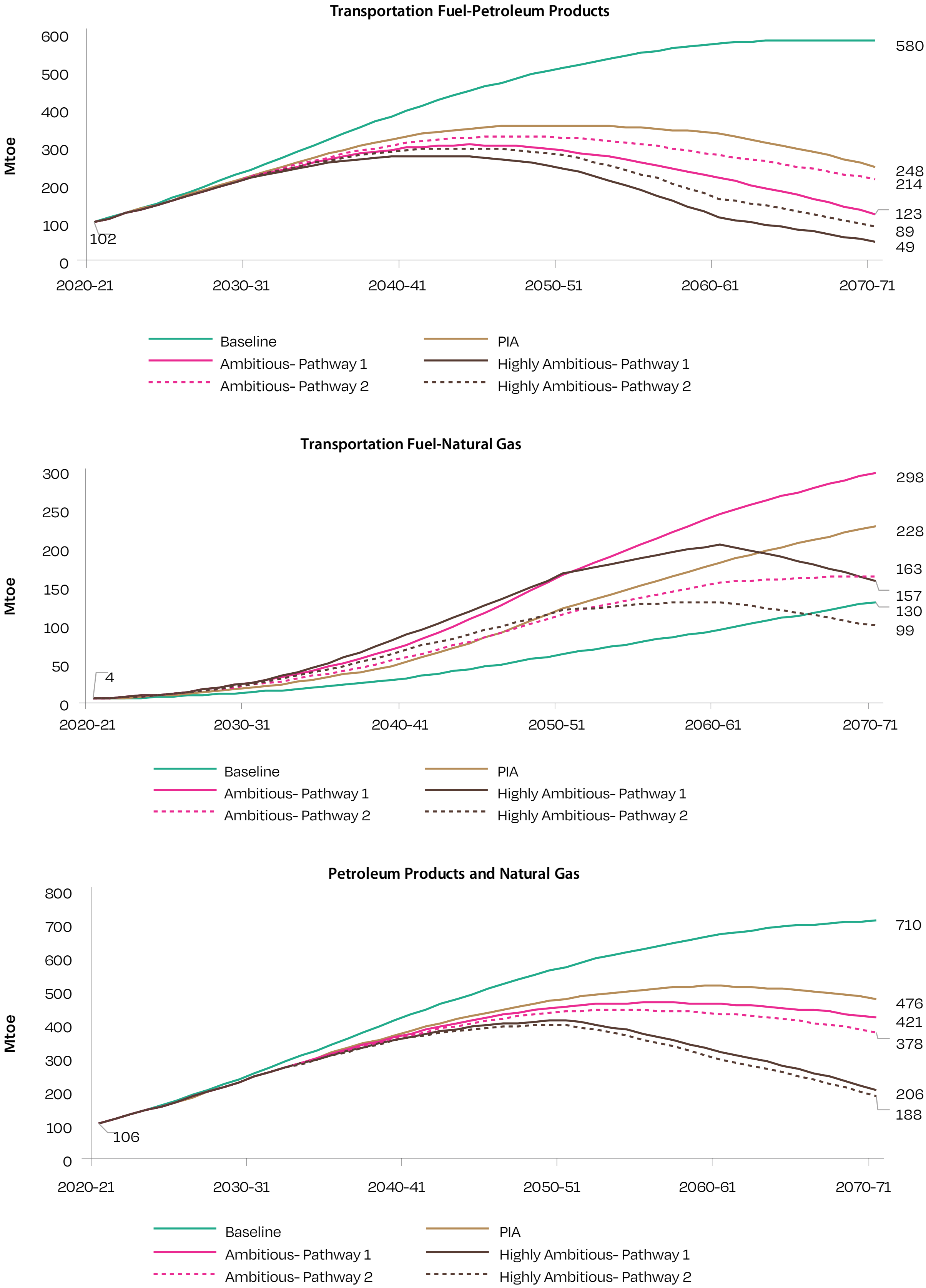
Source: TERI

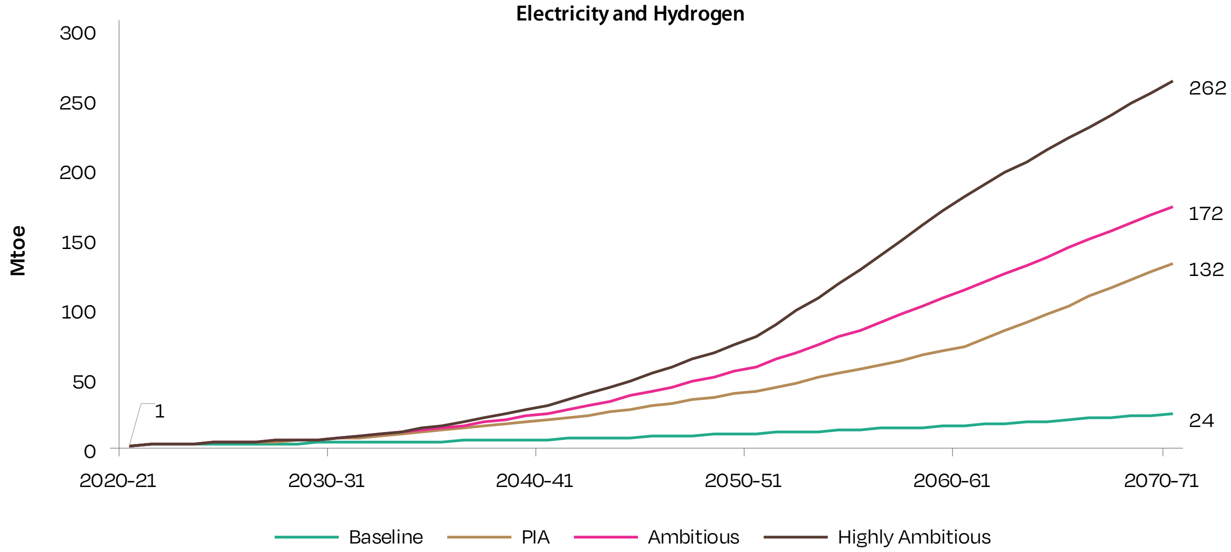
- Compared to the baseline, PIA pathway is expected to reduce petroleum product (petrol, diesel, LPG, ATF) demand by 7 percent in 2030–31, 30 percent in 2050–51, and 57 percent in 2070–71.
- **The impact of the Ambitious pathway** is much greater in terms of **reduction in demand for petroleum products,** by 8–9 percent in 2030–31, 36–43 percent in 2050–51, and 63–79 percent by 2070–71.
- Under the Highly Ambitious scenario the demand for petroleum product reduces by 9 percent in 2030–31, 45–52 percent in 2050–51, and 85–92 percent in 2070–71.
- **Overall fossil fuel demand for transportation** (petrol, diesel, LPG, ATF, CNG, LNG) **is expected to fall** by 4 percent, 17 percent, and 33 percent respectively, by 2030–31, 2050–51, and 2070–71 under the PIA scenario.
- Under the Ambitious scenario, fossil fuel demand is expected to fall by 4 percent, 21–23 percent, 41-47 percent respectively, in 2030–31, 2050–51, and 2070–71.
- **The Highly Ambitious scenario has the maximum impact of fossil fuel demand,** a reduction of 4 percent, 28–31 percent, and 71–74 percent respectively, in 2030–31, 2050–51, and 2070–71.
- **By 2050–51, electricity and hydrogen demand** as transportation fuels is consequently expected to increase by **4, 6, and 8 times respectively,** under the PIA, Ambitious, and Highly Ambitious scenarios. In **2070–71,** it is expected to increase by **6, 7, and 11 times** respectively, under the PIA, Ambitious, and Highly Ambitious scenarios.

Restructuring of fossil fuel demand in transport

A visible shift from petroleum products to natural gas as transportation fuel.

Figure 7: Fuel demand in Indian transport sector





Source: TERI

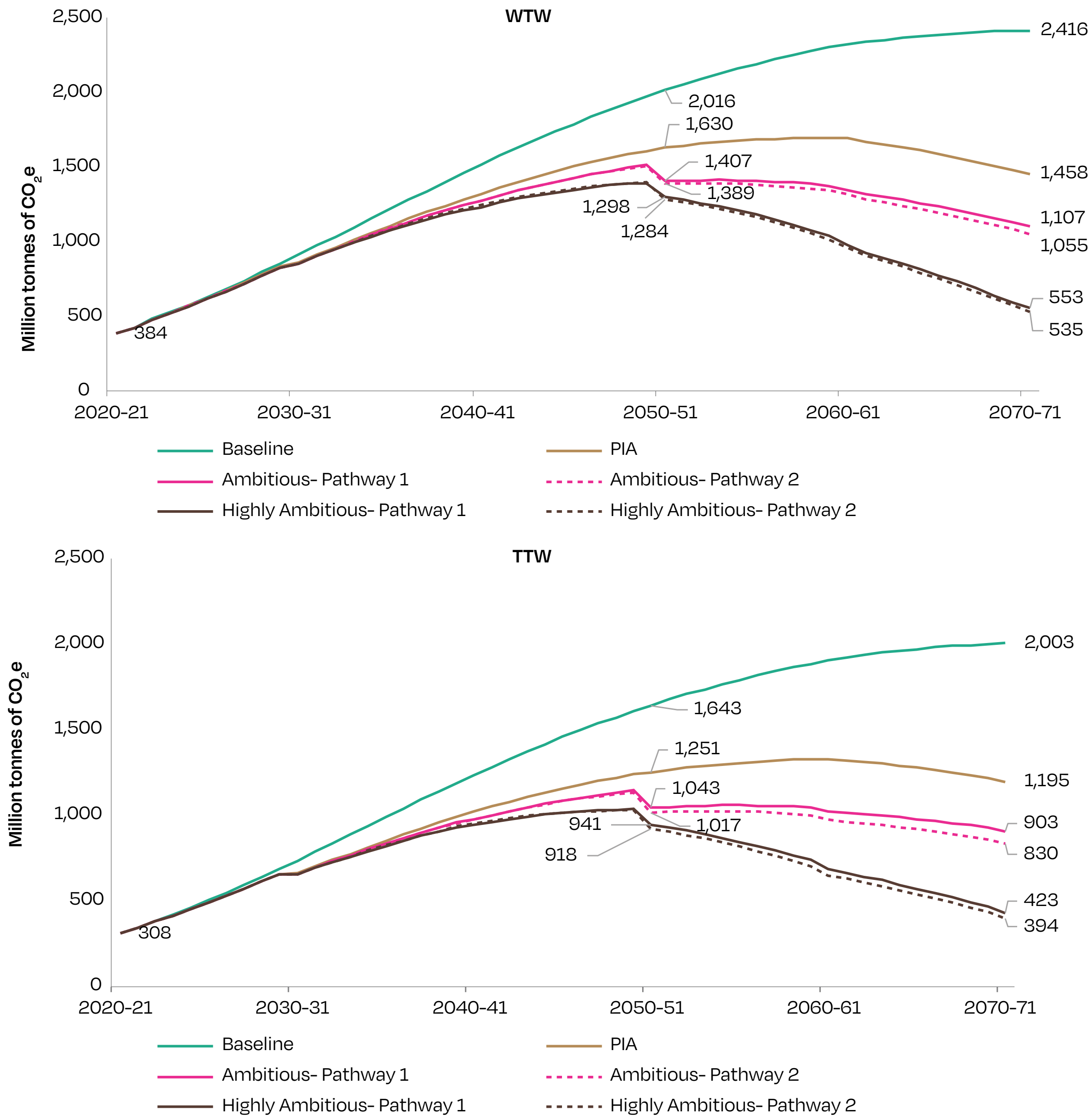
Table 3: Fuel demand

Scenario	Year	Fuel Demand						
		Petrol	Diesel	ATF	CNG	LNG	Hydrogen	Electricity
		Million Tonnes						Terawatt-hour
2020-21		29	63	2	3	0	0	11
Baseline	2030-31	65	140	18	10	0.4	0	37
	2050-51	114	323	38	43	7.4	0	115
	2070-71	109	394	39	82	22.8	0	275
PIA	2030-31	53	124	17	13	0.9	0	68
	2050-51	68	208	35	75	18.6	2.1	402
	2070-71	25	165	31	124	52.6	19.9	871
Ambitious-Pathway 1	2030-31	53	119	17	16	3.1	0.2	68
	2050-51	52	158	28	84	38.7	4.6	518
	2070-71	0	77	16	115	104.6	26.0	1,138
Highly Ambitious-Pathway 1	2030-31	53	119	17	16	3.1	0.2	67
	2050-51	42	131	28	83	41.6	9.7	602
	2070-71	0	13	16	48	70.0	44.1	1,578
Ambitious-Pathway 2	2030-31	53	121	17	15	1.6	0.2	68
	2050-51	60	179	28	66	18.7	4.6	518
	2070-71	23	129	16	77	40.6	26.0	1,138
Highly Ambitious-Pathway 2	2030-31	53	120	17	16	1.9	0.2	67
	2050-51	51	150	28	65	23.0	9.7	602
	2070-71	15	30	16	29	45.7	44.1	1,578

Source: TERI

- **Increased use of natural gas also provides expanding opportunity,** portraying a substitution from primarily a petroleum-based to a primarily gas-based transportation.

Figure 8: GHG emissions



Note: Only green hydrogen is considered in the model due to the unavailability of emission factors for other types of hydrogen. Please refer to Table 6.2 in the main report for detailed assumptions.

Source: TERI

- **All the three alternative scenarios** have WTW GHG **emission abatement potential of 6 percent by 2030–31,** as compared to baseline emissions.
- PIA scenario has WTW GHG emission abatement potential of 30–31 percent by 2050–51 and 40 percent by 2070–71, over baseline emissions.
- The Ambitious scenario has WTW GHG emission abatement potentials of 31 percent by 2050–51 and 54–56 percent by 2070–71, over baseline emissions.
- **The Highly Ambitious scenario** has WTW GHG **emission abatement potentials** of **36 percent by 2050–51** and **77–78 percent by 2070–71**, over baseline emission estimates.

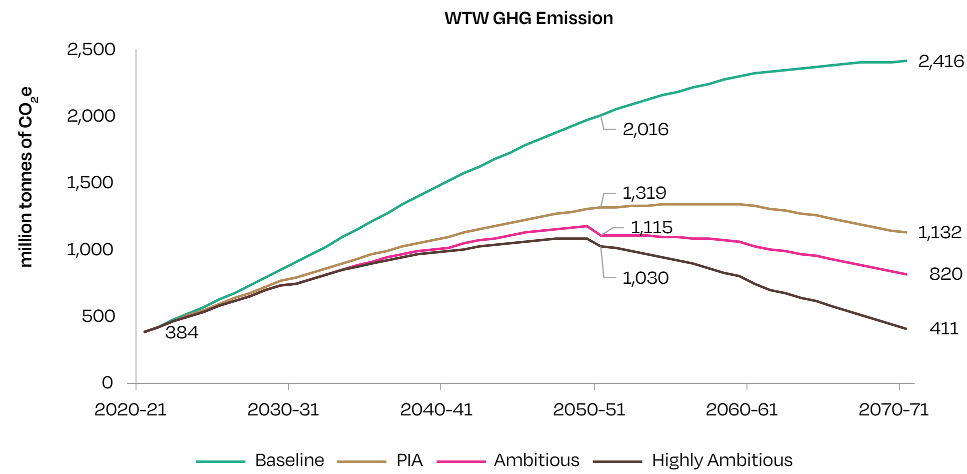
Case Study– Expanding Share of Railways

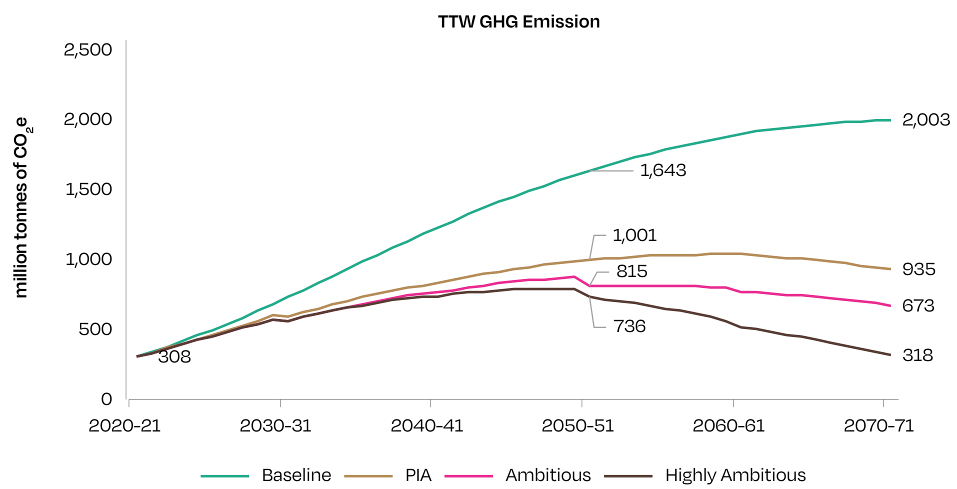
The share of railways in total freight transport has fallen below 30 percent by 2022. However, Indian Railways has planned to invest in various policies to attract freight loading on to its network, resulting in a **45 percent freight share in India. Any intermodal shift to the railways will be largely from the medium and heavy-duty trucks,** plying on longer routes. With an **exogenous assumption on a modest rise in the share of railways to 35 percent in 2030–31 and 45 percent by 2040–41** (under the PIA scenario), additional **emission reduction** of **8 percent by 2030–31, 19 percent** in **2050–51,** and **22 percent in 2070–71** can be achieved compared to the baseline estimates of transport sector emissions. Further, if **aggressive attempts** are undertaken to expand **rail freight share to 45 percent in 2030–31** and **50 percent by 2040–41,** it could result in additional GHG **emission reduction** of **12 percent, 21 percent,** and **26 percent,** respectively, in **2030–31, 2050-51,** and **2070–71,** under the Ambitious and Highly Ambitious scenarios.

Dependence on fossil fuels for transportation purposes will continue but will largely be substituted by electricity and hydrogen.

The Highly Ambitious scenario holds great potential for decarbonisation of the sector.

Figure 9: GHG emission reduction impact of expanding share of railways in freight





Source: TERI

EV Transition–Battery Requirements

- Under the different scenarios, the total **EV projection** ranges between **220–858 million units,** and the corresponding **EV battery demand** ranges between **4.5–23.5 TWh by 2070–71** in the baseline and three alternative scenarios.
- With the increasing adoption of EVs across the passenger segments, **around 70 percent of the battery energy demand would be from passenger transport,** particularly from 4Ws.
- **MHGVs** will drive the demand for EV battery energy requirement in the freight segment, i.e., **10–29 percent** of the total road transport battery demand in the four scenarios.
- In lithium-ion nickel manganese cobalt (NMC) batteries, among the critical minerals, **nickel requirement is highest** with 72 percent of the total mineral requirement for the cathode, **followed by lithium,** i.e., 11 percent, and 9 percent cobalt and manganese.
- These high-nickel batteries would require 0.6 and 4.6 million tonnes in 2050–51, and 1.5 and 10.1 million tonnes in 2070–71 of lithium and nickel in PIA scenario, respectively.
- In the Ambitious scenario, there would be a requirement of 0.8 and 5.6 million tonnes in 2050–51, and 1.9 and 12.7 million tonnes in 2070–71 of lithium and nickel, respectively.
- In the highly ambitious scenario, 1.0 million tonnes of lithium and 7.0 million tonnes of nickel in 2050–51 and 2.6 million tonnes of lithium and 17.6 million tonnes in 2070–71 will be required to meet the EV demand.
- Corresponding to EVs on-road, **the lithium demand in PIA would be 201 percent higher, 287 percent higher in the Ambitious scenario, and in the Highly Ambitious scenario 425 percent higher,** compared to the baseline scenario. The supply chain of critical minerals can be made circular through cost-effective battery recycling technologies.

Table 4: Number of EV batteries in different scenarios (millions)

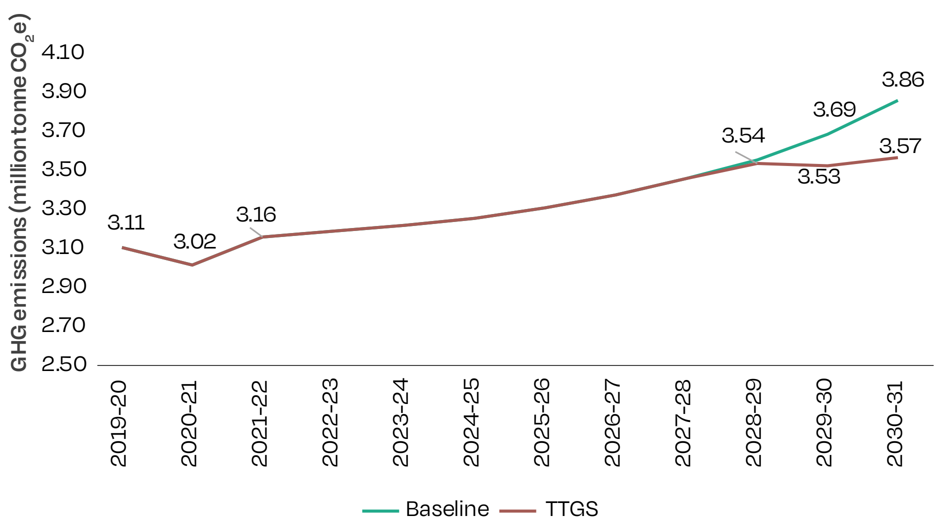
	2W	3W	4W	Bus	LGV	MHGV
Baseline						
2030–31	12.9	0.6	1.4	0.02	0.4	0.05
2050–51	68.8	6.0	27.4	0.08	3.2	0.7
2070–71	202.7	17.4	99.8	0.2	8.0	2.0
Policy-in-Action						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2050–51	335.9	16.4	114.3	1.0	5.6	5.5
2070–71	570.6	52.8	257.2	1.8	12.7	13.2
Ambitious						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2050–51	353.9	24.9	148.8	1.3	8.1	8.1
2070–71	760.3	52.8	307.3	2.0	19.4	19.8
Highly Ambitious						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2050–51	450.4	27.5	164.9	1.5	10.8	9.7
2070–71	760.3	52.8	407.6	3.0	32.8	30.6

Source: TERI

Snapshot– Coastal Shipping

- With the increase in economic activity, **coastal cargo traffic is expected to grow to 1.7 times in 2030–31, as compared to 2021–22.**
- In Indian coastal shipping, **LNG** and derivatives of green hydrogen like **green ammonia/green methanol** are going to be key players in the decarbonisation of shipping. It is expected that the adoption of LNG and green ammonia (under the **Transition to Green Shipping, TTGS** scenario) could result in a GHG emission **reduction (well-to-wake) of 7.5 percent in 2030–31** compared to the baseline scenario. The emphasis forward is expected to be on derivatives of green hydrogen and LNG is likely to act as a transition fuel due to high GHG emissions in terms of complete life cycle.

Figure 10: GHG emissions by Indian flag vessels on coastal operation in 'transition to green shipping'



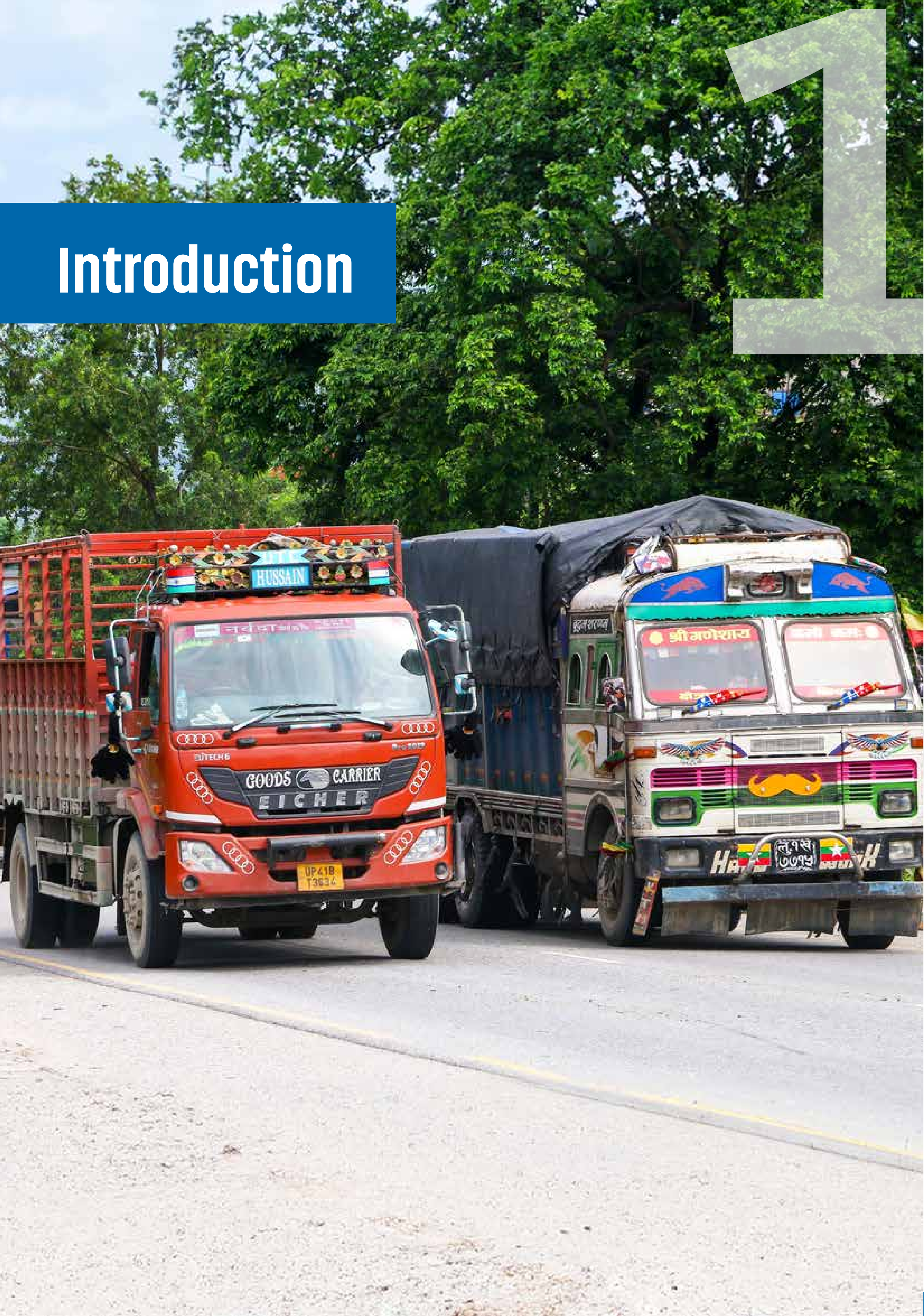
Source: TERI

Key Messages

- India's GDP and population are expected to continue with their growth trajectories, but growth of GDP is expected to dominate population growth. As a result, **transport demand will continue to grow. A four-times increase in passenger demand and 12-times increase in freight demand** between 2019–20 and 2070–71 are expected.
- **Number of passenger** vehicles is expected to grow from 193 million in 2019–20 to 897 million in 2070–71, **a growth of 4.6 times.** It will result in a **road PKM growth** from 6,098 BPKM to 29,251 BPKM, a **4.8 times increase.**
- **Number of goods vehicles** is expected to grow from 11 million to 69 million between 2019–20 and 2070–71, **a growth of 6.5 times.** However, the **road freight demand** is **expected to grow 15 times** from 1,974 BTKM in 2019–20 to 29,766 BTKM in 2070–71.
- With passenger transport demand being driven massively by private ownership of vehicles, especially cars and jeeps, **it becomes extremely important to act towards encouraging public transport.**
- **Fossil fuel will continue to play important role in India's transport sector,** though alternative fuel technologies will grow manyfold. Even under the Highly Ambitious scenario, the fossil fuel demand for transportation will start declining starting 2050–51 and reaching below the 2030–31 demand level by 2070–71.
- **Fossil fuel demand** is expected to range **between 188 and 206 Mtoe in 2070–71,** even under the aggressive transport decarbonization **(Highly Ambitious)** scenario.
- **Natural gas will dominate** the fossil fuel demand for transport sector, replacing the usage of petroleum products. Under the **Highly Ambitious** scenario, **natural gas demand** is expected to range **between 99 and 157 Mtoe in 2070–71.**
- Combined **demand for electricity and hydrogen** as transportation fuels is expected to increase to **262 Mtoe by 2070–71** under the **Highly Ambitious** scenario.
- **Over 60 percent of fuel demand** in 2070–71 is expected to be on account of **freight transport**.
- **Four-wheelers are expected to account for 52 percent of battery energy demand by 2070–71.**
- Government and private players must collaborate extensively to improve the frequency and scale of public transport services to reduce road congestion, overcrowding, and ensure social and environmental gains for all.
- With the increasing transport demand and corresponding rising

- fuel demand, **the emphasis for transport decarbonisation lies in the increased adoption of cleaner fuels.** Solar rooftop charging can be explored for reducing dependence on grid and reduce GHG emission from use of electricity for EV charging.
- In case of transportation sector, **the adoption path of hydrogen as fuel is likely to start with use of grey hydrogen at the beginning,** to capitalise on its cheaper cost of production, followed by use of blue hydrogen in the medium-run, ultimately transitioning to green hydrogen as the prices become cheaper in the long-run.
- **Green hydrogen supply chain security** through international collaboration for fuel and critical minerals for fuel cells, needs to be strengthened where much of it is imported.
- **The fuel cell technology is at a very nascent stage.** For a transition like that of EVs, scaled-up demand incentives should be guaranteed for considerable periods, post pilots, across all stakeholders, to minimize investment risks.
- While the **electric vehicle technology** has started getting adopted in India, its **penetration is still very low in freight segment.** Further, mass adoption of electric vehicles requires massive expansion of charging infrastructure, technological advancements in battery technology, reduction in charging time without compromising battery health. **Hydrogen as transportation fuel is still at a very early stage of technological development.** But railways with over 90 percent of track electrification offers an existing solution to GHG emissions from transport. In addition to the emission abatement potential of railways in freight transport, inducing modal shift to railways for passenger traffic can further add to the **potential of railways in overall transport decarbonisation.**
- Infrastructure development needs to be put into action extensively by all stakeholders to meet the biofuel blending mandates. Long-term data inventories based on forecasts should be prepared for biofuel requirements to **manage food security, resource availability, and livelihoods.**
- With increasing transport demand, in the ambitious scenario, the GHG emissions would increase three times, from 391 million tonnes of CO_2e in 2019–20 to 1,130 million tonnes of CO_2e in 2070–71. The transport sector, which consists of hard-to-abate segments such as MHGV; aviation; and waterways; in isolation would not be able to achieve net-zero emission target by 2070–71. **Carbon credits, carbon offsetting measures, and combined efforts from different sectors of the economy should be adopted to achieve net-zero.**

1 Introduction



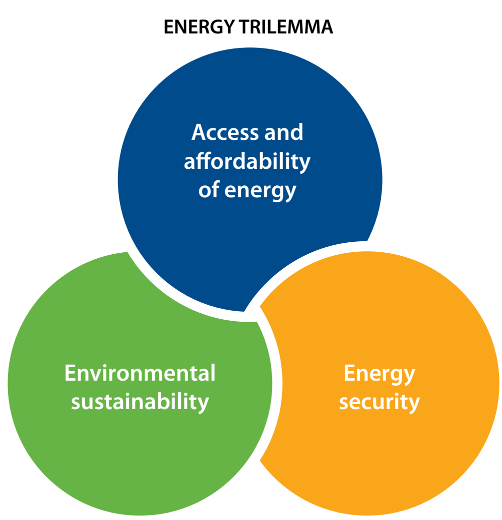
1.1 Background

Transport sector plays a crucial role in development of a nation, by providing access to public space, essential services, and opening newer avenues of employment opportunities (direct and indirect). Railways for example have been pivotal in industrial revolution and associated economic prosperity. Despite the existence of fuels like natural gas and new technologies like electric and hybrid vehicles, hydrogen as fuel, the overwhelming contribution of petroleum to transport sector is undeniable. The alternative fuel technologies have been relatively more expensive for a long time and that has been pivotal to the unprecedented growth of petroleum product demand for transport sector.

Under the Paris Agreement different countries have committed 'net-zero' targets. To complement the net-zero goals set by different countries, considerable mitigation efforts are put to decarbonise transport sector through multitude of policies– promoting non-motorised transport, active promotion of electric vehicles (EVs), consideration of hydrogen as fuel, biofuel blending with petroleum products, increasing market share of rail, investments in mass-transit, etc.

In this regard, addressing the **energy trilemma** – providing **access to affordable energy** to the citizens; ensuring **energy security** through secure supplies; and providing energy systems that are **environmentally sustainable**, is of particular concern for developing countries due to their limited access to resources, existing inequality in social fabric, and their population pressure. India's ambition to elevate itself to the status of a developed country by 2047 requires huge developmental and infrastructural expansion over the next two decades. For a large and populous country like India, it is imperative to strike a balance between energy equity, security, and environmental sustainability.

India has been historically dependent on fossil fuels for energy production and generally maintaining affordability of access to energy. However, the usage of fossil fuels has negatively affected the environmental sustainability aspect of India's economic growth making India the third largest emitter of greenhouse gases (GHG). With adoption of different mitigation strategies to address primarily the environmental sustainability aspect, India may be susceptible the cost dynamics of these new technologies compared to the developed countries and the energy security aspect may metamorphose into a new dimension of energy insecurity, if a large source of alternative energy technologies is not indigenised.



India's ambition to achieve net-zero emissions by 2070 and reduce overall carbon-intensity is associated with the transport sector of the country, which contributes to 12 percent of total CO_2 emissions from energy use[1], of which road transport accounts for 90 percent of the greenhouse gases (GHG) emissions.[2] The structural and demographic characteristics of an economy determine the 'derived demand' of the transport sector (Government of India, GoI). Economic expansions in different sectors

[1] IEA (2023)

[2] Details available at https://iced.niti.gov.in/climate-and-environment/ghg-emissions/energy

will have different impacts on the transport sector of any economy. Similarly, demographic distribution usually has a significant impact on transport demand, where a greater share of working population would imply higher demand for transport (GoI).

Table 1.1 shows the compound annual growth rate (CAGR) of transport demand, energy, and GHG emissions for decadal years 1990–91 to 2019–20. Passenger transport demand (billion passenger kilometres, BPKM) saw a constant growth which witnessed a decline in 2010–11 to 2019–20 decade. However, freight demand (billion tonne kilometres, BTKM) witnessed a huge increase in the period 2000–01 to 2009–10 and declined in the following decade. Similar trend was observed in case of GDP growth. Passenger and freight transport demand have witnessed almost similar growth (CAGR) as that of GDP in the decade of 2010–11 to 2019–20. Growth in energy and emissions has continued to rise over the years.

Table 1.1: CAGR in transport demand, GDP, energy demand, and GHG emissions (%)

Period	Transport Demand[a,b]		GDP	GDP per capita	Energy Demand	GHG Emissions
	BPKM	BTKM				
1999–2000/1990–91	8.4	3.7	5.5	3.5	6.5	6.2
2009–10/2000–01	8.4	7.8	7.2	5.5	8.4	8.2
2019–20/2010–11	6.3	6.4	6.4	5.1	8.5	8.3

Note: [a] Includes road, rail, and aviation segments. [b] The data for aviation was available since 1993–94, hence BPKM for aviation have been back-casted for periods preceding 1993–94 to establish uniformity.

Source: TERI Analysis based on data from Ministry of Road Transport and Highways (MoRTH), Ministry of Railways, Ministry of Civil Aviation; GDP data is sourced from OECD

The period from 1990 to 2010 witnessed rapid expansion in motor vehicles (MVs) particularly in cities such as Delhi, Ahmedabad, Bangalore, and Chennai (Badami & Haider, 2007). The reasons for this rapid growth in passenger transport demand can be attributed to increased economic activity and household income, entry of new firms in the automobile sector resulting in product differentiation due to liberalization in the early 1990s, and availability of finance at low interest rates boosting sales of private vehicles (Singh, 2006). Table 1.2 shows the CAGR for vehicle categories for different time periods and population.

Table 1.2: CAGR for different vehicle categories and population (%)

Period	Vehicle Categories						Population
	2Ws	Cars, Jeeps & Taxis	Buses	Goods Vehicles	Others	Total	
2001/1991	10.5	9.1	6.7	8.1	8.6	9.9	2.0
2011/2001	10.2	10.5	9.7	9.1	7.6	9.9	1.5
2019/2009	10.4	9.6	3.3	8.6	7.6	9.9	1.2

Note: Others include three-wheelers (passenger/LMVs), tractors, trailers, and other miscellaneous vehicles.

Source: CAGR for vehicle categories is sourced from Road Transport Yearbook (2019–20), MoRTH, 2023; Data for population is sourced from United Nations Department of Economic and Social Affairs, Population Division, 2023

The freight demand growth has been similar to GDP growth for the decade of 2010–11 to 2019–20. The higher growth in freight demand is associated with a boost in the demand of goods due to improved income levels, e-commerce, and retail markets (NITI Aayog & RMI India, 2021). Twenty-two percent of the freight movement is constituted by agricultural produce, 39 percent by mining goods, and 39 percent by manufacturing commodities (NITI Aayog & RMI India, 2021). The period 2000–01 to 2009–10 even witnessed a CAGR of 15 percent and 9.7 percent of cargo carried in case of inland waterways and coastal shipping respectively. This was primarily due to the increased trade in terms of exports and imports between 2000–01 to 2009–10 at a CAGR of 16.3 percent and 19.6 percent respectively.[3] This required freight to be transported through water from production hubs to ports and *vice-versa*. Another reason was the increased growth in goods vehicles during this period as reflected in Table 1.2.

Box 1: Role of transport– Pre and post COVID-19

Table B1 shows the contraction in final energy consumption for the year 2020–21 as compared to 2019–20 across multiple sectors due to COVID-19 and growth post the pandemic in the year 2021–22. The final energy consumption witnessed a contraction of 5.4 percent in 2020–21 as compared to 2019–20 and showed recovery by growing at a positive rate of 3.8 percent. With transport corresponding to a share of 11 percent in the final energy consumption as indicated in Figure B1, transport has contributed significantly to the corresponding decline in the total final energy consumption in 2020–21. This is indicative of the fact that decarbonising of the transport sector is important for reduction in energy usage and correspondingly mitigation of GHG emissions.

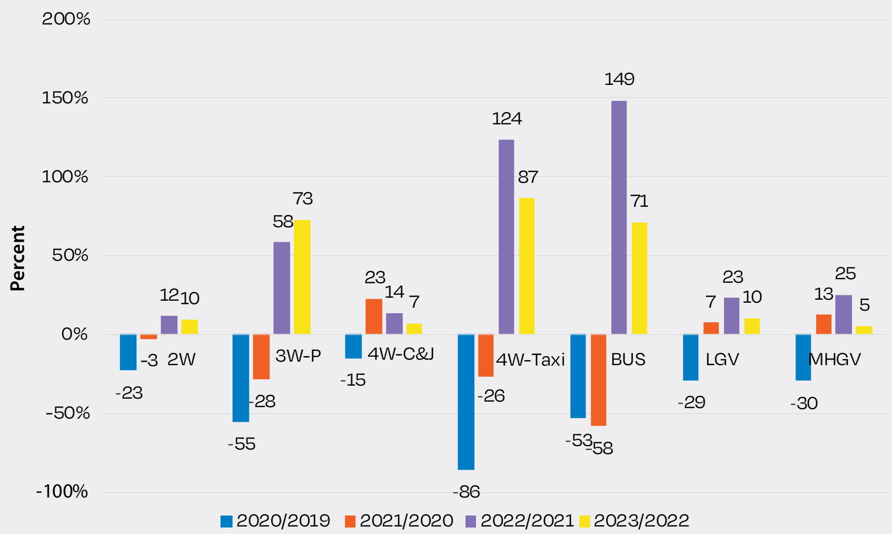
Table B1: Growth in transport demand, GDP, and final energy consumption (%)

Period	Transport Demand		GDP	Final Energy Consumption					
	BPKM	BTKM		Industry	Transport	Residential	Commercial and Public Services	Agriculture/ Forestry	Total
2020-21/ 2019-20	-6.3	-2.7	-4.2	-4.5	-19.0	6.6	-18.0	4.2	-5.4
2021-22/2020-21	11.6	16.5	8.8	0.7	17.9	0.7	23.4	3.0	3.8

Source: TERI Analysis for BPKM and BTKM based on data from MoRTH, Ministry of Railways, Ministry of Civil Aviation; GDP data is sourced from OECD; Sectoral Final Energy Consumption is sourced from Energy Statistics 2023, MOSPI

As shown in Figure B1, registrations of taxis witnessed the highest decline in 2020, as compared to 2019, followed by three-wheelers (passenger) (3W-P). Private cars (and jeeps) suffered the least during the same period. Registrations of two-wheelers, 3W-P, taxis, and buses continued to fall in 2021. New buses registered in 2021 were 38 percent less than those in 2020. Recovery in vehicle registrations for cars (and jeeps) and goods vehicles began in 2021 while all other segments started recovering in 2022. In the year 2023, taxi registrations grew the highest (by 87 percent) and medium and heavy goods vehicles grew the least (by 5 percent) when compared to 2022.

Figure B1: Growth in annual registrations of different vehicle segments



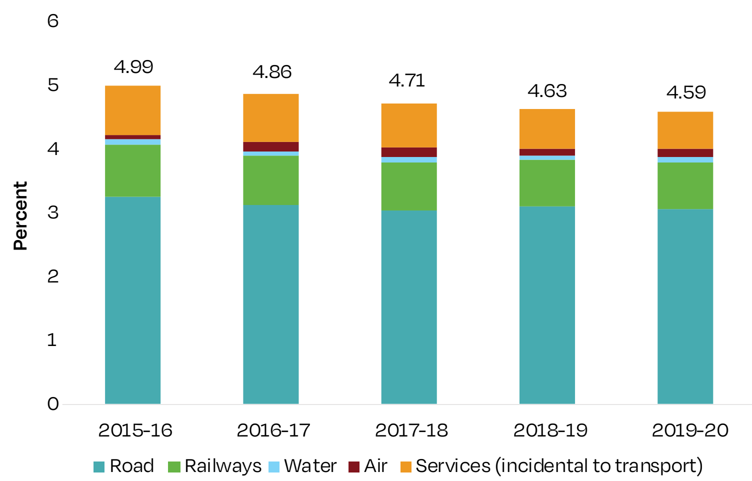
Source: TERI's analysis based on data from Vahan Dashboard

[3] https://stats.wto.org/

1.2 Multimodal Transport

Post the COVID-19 pandemic, with easing of travel restrictions, transport services contributed significantly to high service imports accompanied with high cost of transportation due to capacity shortages (Ministry of Finance, 2023). Time and monetary costs involved in end-to-end transportation in a diverse country like India can be reduced by developing multimodal transport availability and infrastructure and facilitating last mile connectivity. This is reckoned with in the vision of PM-Gati Shakti of connecting business clusters and leveraging technology in India's logistic sector (NITI Aayog, 2021). Figure 1.1 shows the shares of different modes in the Gross Value Added (GVA) over a period of five years (MoRTH, 2023).

Figure 1.1: Mode-wise contribution to GVA



Note: Base year is 2011–12.

Source: MoRTH Road Transport Yearbook (2019–20)

1.2.1 Roads

Indian road network comprises of national and state highways, and district, urban, and rural roads supporting intermodal connectivity. Road network expanded at a CAGR of 3.5 percent between the years 2009 and 2019 (MoRTH, 2023) and has continued to attract investments. Within this, rural road network expanded at a CAGR of 5.6 percent (MoRTH, 2023). Eighty-seven percent of the total passenger[4] and 65 percent of total freight movement are handled by road transport (Ministry of Railways, 2020).[5] According to the World Road Statistics, 2020, India ranks eighth in total in-use vehicles, eighth in passenger cars, third in buses and motor coaches, and first in motorcycles and mopeds (MoRTH, 2023).

However, road transport is plagued with certain challenges such as– severe congestion in cities which leads to delays and loss in quality of economic output being transported (Ministry of Finance, 2023). The number of motor vehicles (MVs) has grown at a higher rate (CAGR of 9.9 percent between 2009 and 2019) than the road network expansion (MoRTH, 2023). Though India lacks in terms of ownership of vehicles (only 8 percent of households owning four-wheeler and 54 percent of the households owning two-wheelers in 2019-21, IIPS & ICF, 2021), the share of households owning two-wheelers and four-wheelers have increased considerably between 2001 and 2011, by 79 percent and 88 percent respectively (Dhar et al., 2017).

[4] Details available at https://morth.nic.in/road-transport

[5] This is pertinent to the year 2017-18.

Unplanned and uncontrolled development with low land-use controls contributed to increased number of trips and/or greater length of trips, even in the case of public transport (PT) (Pucher et al., 2004). PT covers 30 percent of the urban trips in India (IEA, 2023), however, the required bus stock to cover such trips is quite low. According to TERI estimates, with an average life of 15 years for a bus in India, in 2019, in cities one bus catered to to 891 people.[6] For shorter trips and areas with less developed public transport, auto-rickshaws, and taxis have enabled first and last-mile connectivity and have continued to be used extensively within cities. According to IEA (2023), 40 percent of the urban trips in India are less than 5 km where non-motorized transport (NMT) could play a crucial role.

1.2.2 Railways

The issues of efficiency (operational and energy) have continued to bring back the emphasis on railways in the Indian transport discourse. The network of Indian Railways (IR) exceeds 68,031 route km making it the fourth largest globally (Ministry of Finance, 2023). In India, 27 percent of the total logistic market depends on railways for transportation (GoI, 2022).

The railways, as a means of national unification and development, have played an important role by contributing high transport activity with low logistics costs. Evidently, logistics costs in India fell in the range of 7.8–8.9 percent of the GDP for the year 2021–22 (NCAER, 2023). Total freight transport costs (including domestic and imported services) constituted 63.5–72.1 percent of the total logistics costs (NCAER, 2023). Out of this, railways accounted for 9.9 percent of the freight transport cost, which is much lower than that of road—which accounted for 63.5 percent of the total freight transport costs (NCAER, 2023). Therefore, it is essential to strengthen the rail transport system as it is cost-effective in comparison to road transport.

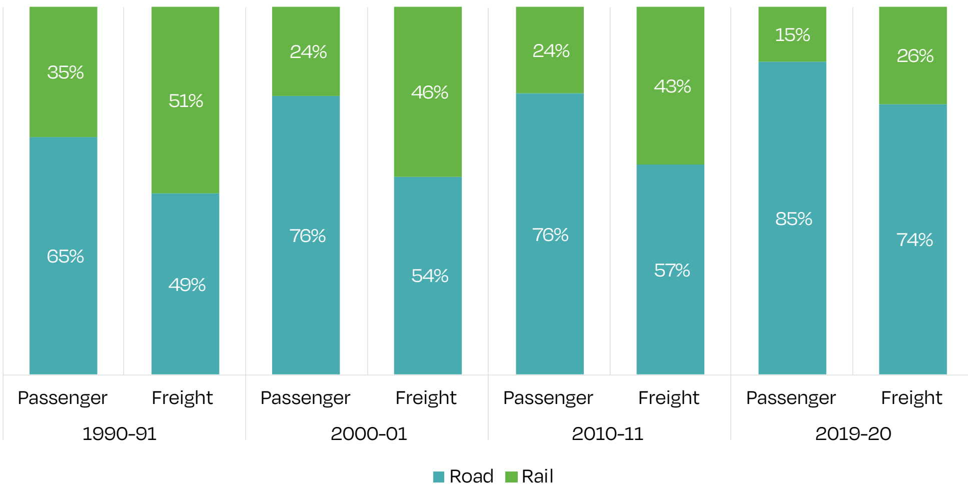
Indian rail freight, however, faces challenges on all fronts; be it operational, infrastructural, or financial. Slow speed trains coupled with congestion contribute to a high transit time (BRIEF & NITI Aayog). For instance, the Golden Quadrilateral network (connecting metropolitan cities of Delhi, Mumbai, Chennai, and Kolkata) and extending diagonals, are the most occupied network transporting 58 percent of freight and 52 percent of passenger traffic but contribute to only 16 percent of the overall route length (BRIEF & NITI Aayog). Congestion concerns have only aggravated over time with every new passenger service expanding at the cost of freight transport (BRIEF & NITI Aayog).

1.2.3 Modal Shift: Rail to Road

Both passenger and freight transport has witnessed a shift from rail to road, with a continual decline in share of the former as shown in Figure 1.2. This pushes forwards the need for a modal shift towards rail as railways are estimated to be 12 times more efficient in case of freight transport and thrice more efficient in passenger transport (Indian Railways, 2021). The construction of Dedicated Freight Corridors (DFCs) intends to reduce the turnaround time of trains due to simultaneous operation with passenger trains leading to congestion and ensure unmarred freight transport (Gupta, 2023). With almost 80 percent of the DFCs being functional, it will boost the share of railways in freight transport.

[6] Urban population data is sourced from World Bank, Details available at https://data.worldbank.org/indicator/SP.URB.TOTL?locations=IN

Figure 1.2: Share of road and rail in passenger and freight transport demand



Source: TERI analysis is based on data from MoRTH and Ministry of Railways

1.2.4 Aviation and Waterways

Domestic aviation observed a passenger load factor of 90 percent in 2019, which has increased significantly since 2000s; occasionally witnessing a load factor of 50 percent as well (IATA, 2019). Penetration of air transport has been low in India with per capita average number of trips being only 0.08 in 2015 (Hakim & Merkert, 2017).

Waterways are another mode that carries great potential, with abundance water resource in India. Both coastal shipping and inland waterways are cost-effective means of transportation.[7] In 2017–18, coastal shipping and inland waterways contributed 5 percent and 2 percent of total freight activity respectively (Ministry of Railways, 2020). Coastal shipping has the potential to play an important role in multimodal integration of other transport modes, with the Indian coastline extending to more than 7,000 km, and 12 major and more than 200 non-major ports. Coastal shipping contributes significantly to mineral transport and passenger services between the mainland and island territories—Andaman and Nicobar Islands and Lakshadweep. The total inland water stretch is 14,850 km (Ministry of Finance, 2023). Out of 111 National Waterways (NWs), 14 feasible NWs have undergone development wherein the total cargo traffic was 108.8 million tons in 2021–22, which is 30.1 percent higher than the previous year (Ministry of Finance, 2023). Inland water transport can facilitate demand for the tourism sector and be used for the purpose of vehicle carriage.[7] Both coastal shipping and inland waterways can aid in reducing the burden on road and rail freight transport as a supplementary mode.[7]

1.3 Boosting Transport Infrastructure

To achieve the USD 5 trillion GDP target of 2025,[8] India needs to boost transport infrastructure. In this regard, India has shown progress, reflected in developments such as annual incremental increase of national highways—by 29 km/day in 2021–22 compared to 12.1 km/day in 2014–15 (MoRTH, 2023)—coupled with the introduction of 15 new highways in 2022,[8] the Vande Bharat Express, and DFCs. To transport perishables from surplus to deficient areas and to avoid quality loss due to congestion and delays, Kisan Rail trains were introduced in 2020–21(Ministry of Finance, 2023).

[7] Details available at https://shipmin.gov.in/division/iwt-1

[8] Details available at https://www.ibef.org/industry/infrastructure-sector-india

Projects on the aviation sector include renewal of airports and improvement of landing facilities for smooth air connectivity under the *Ude Desh ka Aam Nagrik (UDAN)* scheme (Ministry of Information & Broadcasting, 2023). Projects for waterways aim to enhance operational efficiency of ports, resolving first- and last-mile connectivity problems for ports and decreasing vessel turnaround time under the Sagar Mala Scheme.[9]

1.4 Energy Transition in India's Transport Sector

India's heavy dependence on coal and oil has contributed to increasing CO_2 emissions making it the third-highest contributor to annual CO_2 emissions. However, the per-capita emissions have continued to be low, at par with the low absolute emitters (IEA, 2023). The transport sector constitutes 23 percent of global energy related CO_2 emissions (IPCC, 2014). In case of India, 14 percent of direct (Scope 1) energy-based CO_2 emissions are released by the transport sector (Kumar, et al., 2022). This is a result of the dominance of petrol and diesel as fuels in road transport which also increases the import dependence for crude oil and petroleum products.

To fulfil the net-zero carbon emission target, the Indian transport sector aims to move towards a just transition from fossil-fuel dependency to clean energy utilization, while ensuring energy sufficiency and inclusivity of the nation. India declared its 'Long-Term Low Emission Development Strategy (LT-LEDS)' at COP 27 in November 2022 (Ministry of Finance, 2023), where several strategies concerning Indian transportation were discussed. These included:

- increased penetration of electrification across different modes and vehicle segments,
- increased use of biofuels, especially ethanol blending in petrol to achieve a target of 20 percent by Ethanol Supply Year (ESY) 2025–26,
- developing scope and capacity for the adoption of green hydrogen fuel under the National Green Hydrogen Mission, and
- avenues to achieve modal shifts in both passenger and freight mobility to maximize energy efficiency.

To promote low carbon mobility, rail traction has been electrified extensively, which has picked up pace only in the last nine years (Ministry of Information & Broadcasting, 2023). IR's rail track electrification has been progressing swiftly, with 60,814 km being electrified until November, 2023 and 14 states and union territories (UTs) having 100 percent electrified tracks (Ministry of Railways , 2023). Green hydrogen is also being discussed as a potential low carbon alternative technology for hard-to-abate sectors, like waterways and long-distance freight transport.

1.5 Key Objectives

This study focuses on preparing a low carbon transport technology-driven pathway to enable utilization of less polluting energy sources as fuel. The key objectives of the study are:

- Develop a baseline scenario of different vehicle types across all modes of transport, for assessing fuel demand and GHG emissions
- Analyse different scenarios under alternate fuel technologies, blending prospects, and fuel efficiency improvement, in terms of their impacts on fuel demand and GHG emission abatement potential
- Deliberate on the challenges associated with the low energy transition in transport sector and understand the policy implications of the alternative scenarios

[9] Details available at https://sagarmala.gov.in/about-sagarmala/background

2

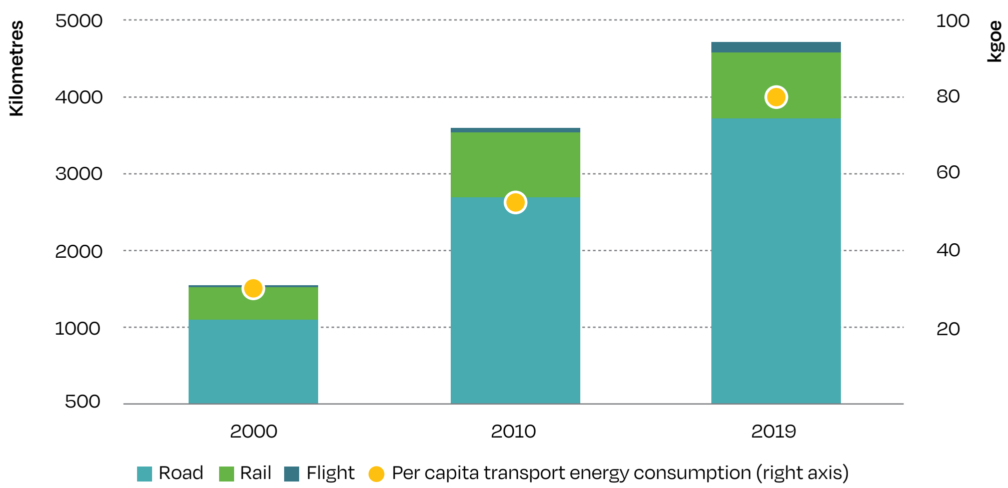
Indian Transport Sector: An Overview

The transport sector in India comprises of distinct modes such as road, rail, civil aviation, coastal shipping, and inland waterways. With increased passenger and freight transport demand the transport sector has become the fastest-growing end-user of energy (IEA, 2022). During the last seven decades, growth in total freight traffic has been broadly consistent with that of GDP, while passenger traffic increase has been much greater (NTDPC, 2014). Both passenger and freight movements were dominated by rail till the 1980s; thereafter, large-scale investment in road infrastructure facilitated connectivity and ease of movement; consequently, the dominance of railways waned. Moreover, increased cost and transit time due to multiple handling of goods in railways, infrastructural constraints at rail terminals, etc., have led to an increase in the share of the road sector (TERI, 2021).

2.1 Trends in Passenger Mobility

For passenger transport in India, rail and road are the dominant modes and the traffic carried by air and water transport is considerably less. The average annual distance travelled per capita (Figure 2.1) has increased threefold and was observed to be nearly 5,000 km each year since 2000 (IEA, 2022). The total share of road passenger traffic (BPKM) in road and rail has increased from 32 percent in 1951 to 90 percent in 2011–12 (NTDPC, 2014). The passenger traffic at Indian ports was a mere 42,000 passenger per day in 2021-22 (MoPSW, 2022). Railways witnessed 9.64 million passengers per day in 2021-22. (Ministry of Railways, 2022).

Figure 2.1: Annual distance travelled per capita in India



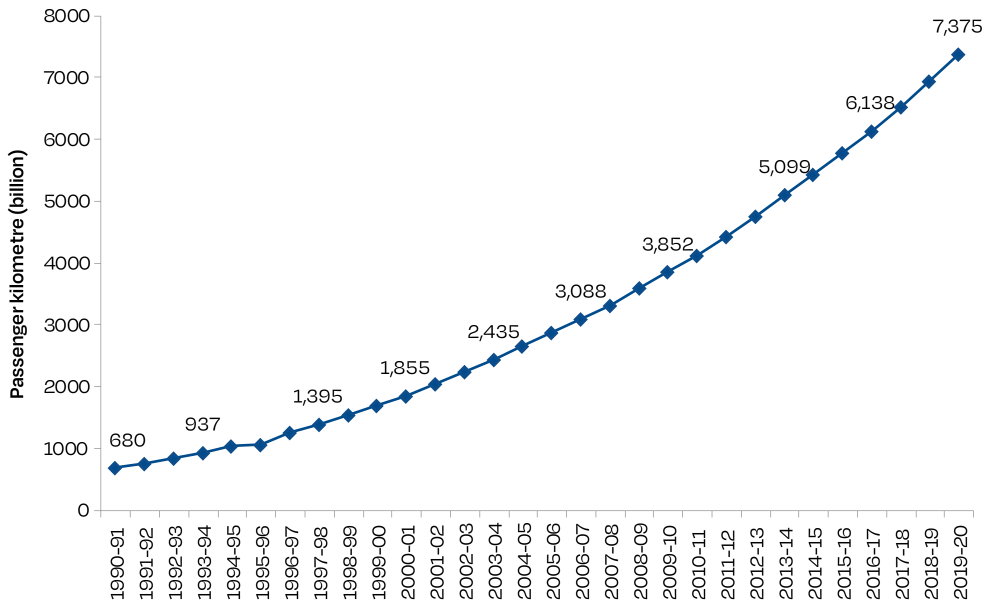
Note: kgoe – kilograms of oil equivalent.

Source: IEA (2022)

2.1.1 Road

In India, road-based passenger mobility has increased at a tremendous pace over the years as shown in Figure 2.2. From 1950–51 to 2019–20, passenger mobility increased from 36 BPKM (Singh S. K., 2006) to 7,375 BPKM (TERI Analysis). Total number of registered non-transport vehicles was nearly 300 million.

Figure 2.2: Trend of passenger kilometre travelled by road

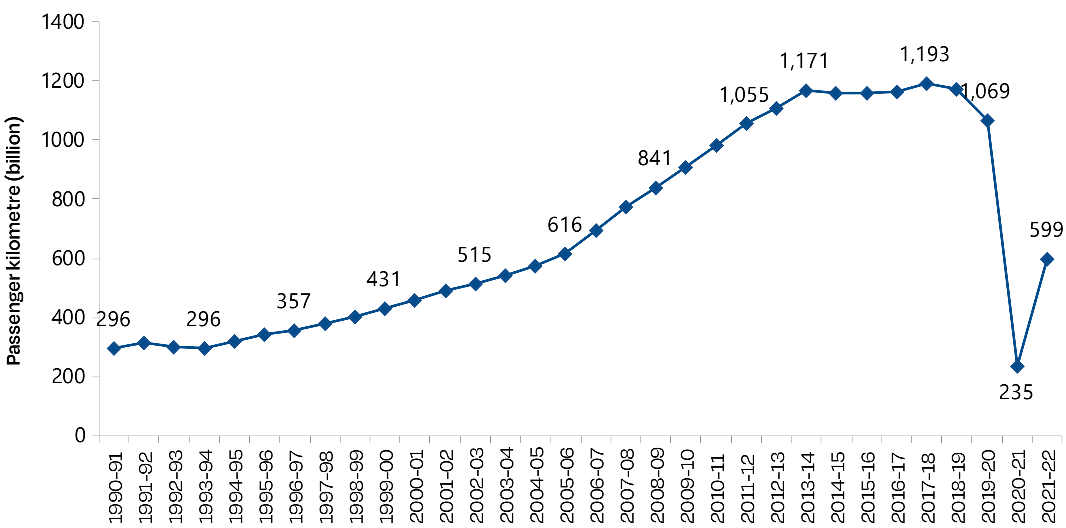


Source: TERI

2.1.2 Railways

Figure 2.3 represents the passenger traffic, which increased from 1,250 million passengers in 2020–21 to 3,519 million passengers in 2021–22 and total passenger kilometre travelled increased from 235 billion to 599 billion during the same duration (Ministry of Railways, 2022). However, the overall share of passenger transport by railways fell from about 70 percent in 1950–51 to about 15 percent in 1999–2000 and to about 10 percent by 2011–12 (NTDPC, 2014).

Figure 2.3: Trend of passenger kilometre travelled by IR

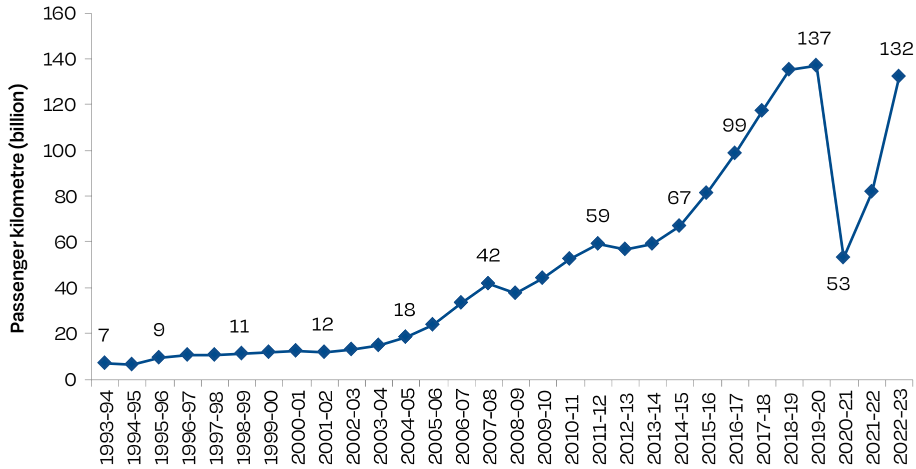


Source: IR Annual Reports

2.1.3 Aviation

India is the third largest civil aviation market in the world (IBEF, 2023). Passenger air traffic has increased at a tremendous pace with the increase in airport infrastructure—from 74 airports in 2014 to 147 airports in 2022 (Directorate General of Civil Aviation (DGCA), 2023)—along with improvements in security, surveillance, and air traffic navigation systems (IBEF, 2023). Domestic passenger traffic has increased at a CAGR of 6.95 percent from FY16 to FY23 (DGCA, 2023), as shown in Figure 2.4. In 2022–23, the domestic passenger traffic witnessed a growth of 61.6 percent compared to the previous year with 136 million passengers carried (DGCA, 2023).

Figure 2.4: Trend of domestic air passenger traffic



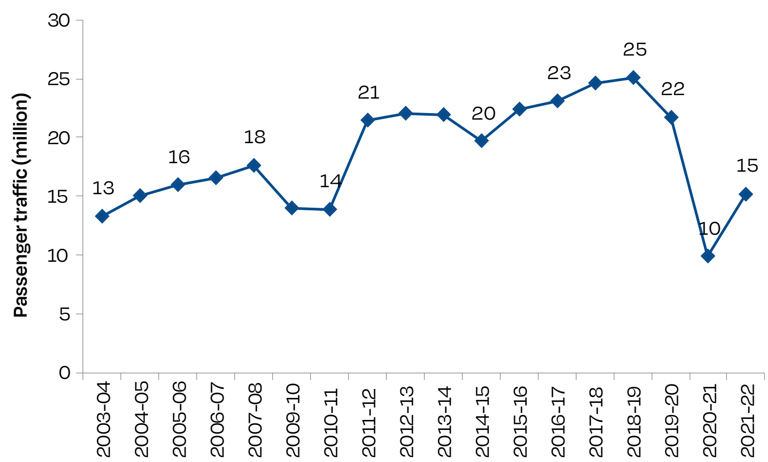
Source: Handbook of Civil Aviation Statistics

2.1.4 Waterways

Coastal Shipping

The passenger traffic via coastal shipping has witnessed an overall increasing trend but failed to recover to pre-COVID levels. In 2021–22, the passenger traffic was 15.186 million– an increase of 54 percent over the previous year (Figure 2.5). The non-major ports contribute to 98 percent of the passenger traffic, while the share of major ports is a meagre 2 percent.

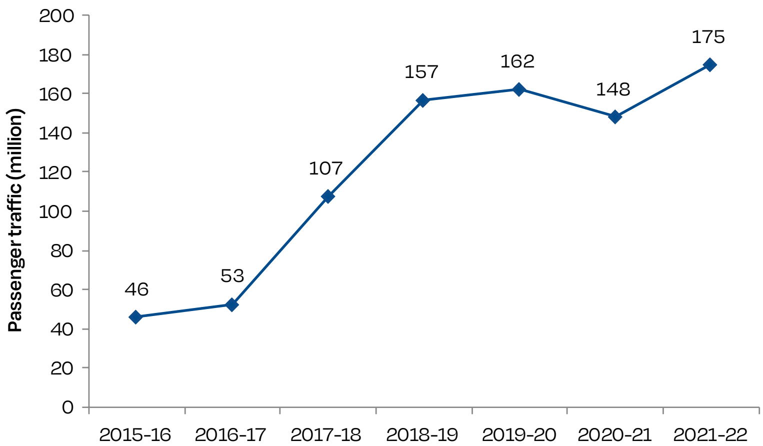
Figure 2.5: Trend of passenger traffic through major and non-major ports



Source: Basic Ports Statistics

Inland Waterways

Figure 2.6: Trend of passenger carried through Inland Water Transport (IWT)



Source: Statistics of Inland Water Transport 2021–22, IWAI

2.2 Trends in Development of Freight Mobility

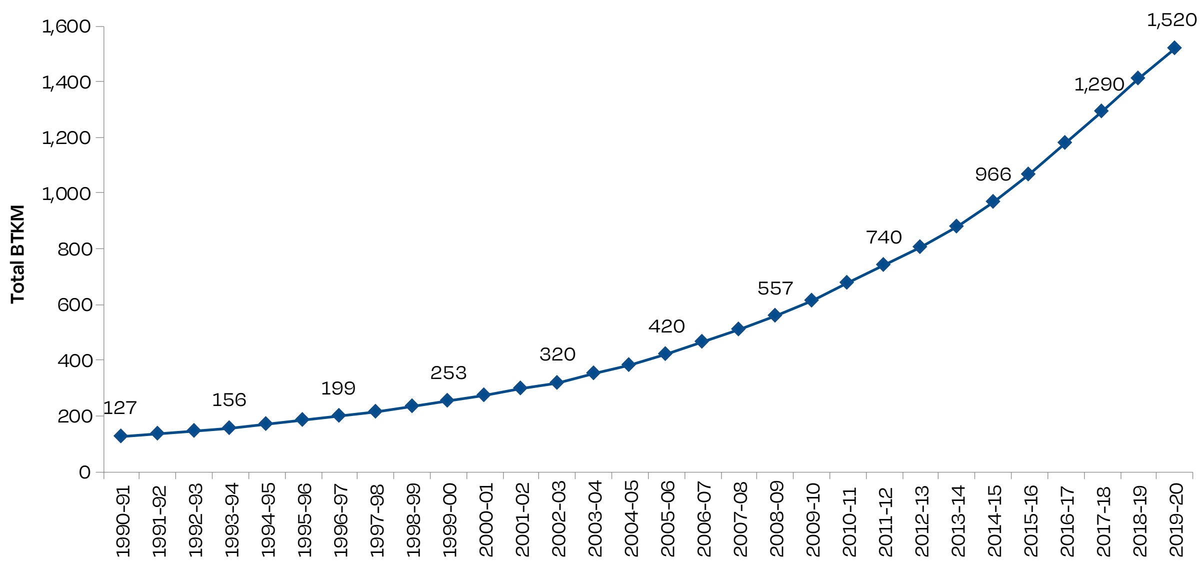
Rail and road dominate freight mobility, as these carried about 87 percent of the total freight traffic in the country in 2007–08 (ADB, 2017). As road infrastructure has expanded rapidly, in 2020, the share of rail in freight transport was 27 percent as compared to road's share of 72 percent.[10] In 2019, the freight movement by road transport was around 1,974 billion tonnes kilometre.[11] The volume of cargo handled across Indian ports in financial year 2021, however, was only around 1.25 billion metric tonnes. Inland water transport on the contrary, accounted for less than 1 percent of the freight traffic.

2.2.1 Road

Freight activity (billion tonne kms, BTKM) has quadrupled between 2000 and 2019 in India (Figure 2.7), alongside a fivefold increase in light commercial vehicles (LCVs) and a thirteen-fold increase in heavy freight trucks (IEA, 2022), with the ability to provide door-to-door services and handling smaller parcel sizes.

[10] TERI
[11] TERI

Figure 2.7: Trend in total BTKM in the road freight

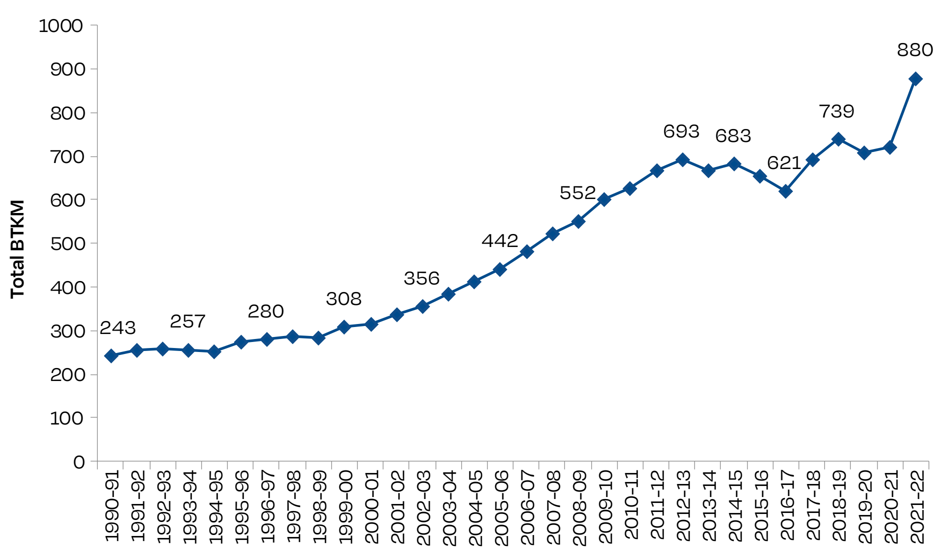


Source: TERI

2.2.2 Railways

Total freight activity has increased over the years with 719 BTKMs carried in 2020–21 to 871 BTKMs in 2021–22, as shown in Figure 2.8 (Ministry of Railways, 2022). However, the share of railways in freight traffic has fallen from about 90 percent in 1950-51 to about 40 percent by 1990s and further to over 30 percent by 2011–12 (NTDPC, 2014).

Figure 2.8: Trend of total freight traffic carried by IR

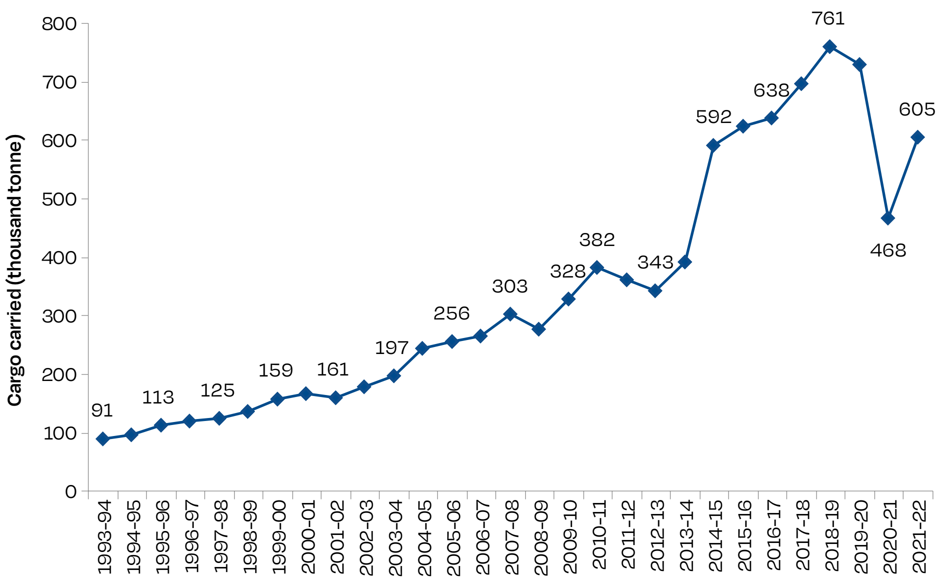


Source: IR Annual Reports

2.2.3 Aviation

Strong macroeconomic fundamentals, growth in e-commerce industry, end-to-end solutions by service providers, growth of new industries such as pharmaceuticals, electronics, and allied services, are the major factors for rapid growth of domestic air cargo (Ministry of Civil Aviation, 2012). In India, cargo movement is mostly concentrated in major hubs of Delhi, Mumbai, Bengaluru, and Hyderabad, with 70 percent cargo volumes passing through these hubs. However, demand for e-commerce in India is largely driven by tier II/III cities (Burroughs et al., 2021).The cargo movement[12] by the aviation sector has grown approximately by 6 times, from 90,591 tonnes in 1993–94 to 6,05,250 tonnes in 2021–22 (Figure 2.9). Of this, 18.5 percent of domestic cargo was carried as belly cargo and the rest of the proportion by dedicated freighters in 2022–23 (Directorate General of Civil Aviation (DGCA), 2023).

Figure 2.9: Trend of cargo carried by the domestic aviation sector



Source: Handbook of Civil Aviation Statistics

2.2.4 Waterways

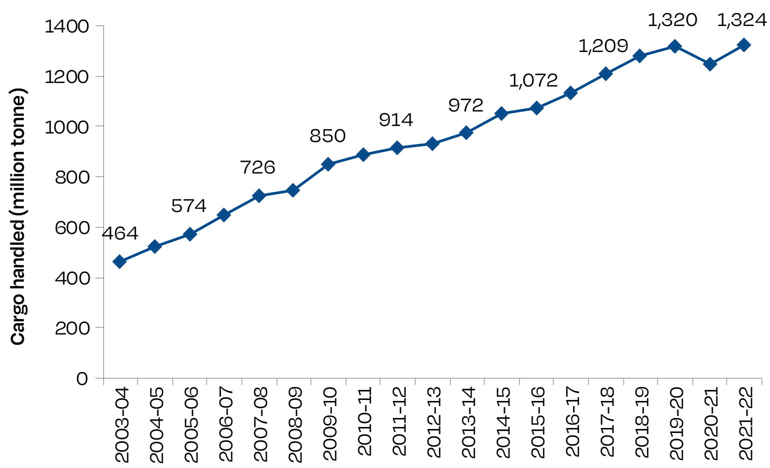
India's maritime trade over the last three decade has seen a steady increase in handling of cargo traffic at Indian ports, which comprises of export-import trade in various bulk and non-bulk commodities (MoPSW, 2022). While 54 percent of the cargo was handled by the major ports with a total of 720.05 million tonnes, the rest 46 percent was handled through non-major ports, i.e., 603.75 million tonnes. At major ports, containers handled were 11.22 million twenty-foot equivalent unit (TEU), or 167.38 million tonnes in 2021–22 (MoPSW, 2022). In 2020–21, a negative growth of 5.3 percent was observed; however, with recovery of the economy in 2021–22, there was an increase by 5.9 percent (Figure 2.10).

Amongst the major ports, Deendayal Port accounted for the highest share of 17.7 percent in the total cargo traffic at all major ports during 2021–22. Petroleum, oil, and lubricants (POL) and their products have been the largest commodity handled by the ports, constituting 27.7 percent of the total traffic (MoPSW, 2022). With improvements—efficiency of major ports, policy initiatives

[12] Cargo carried by the aviation sector consists of freight and mails.

and reforms supporting trade and ease of doing business, along with provision of multi-modal services for logistic movement—the average turnaround time has improved over the years, amounting to 2.22 days in 2021–22.

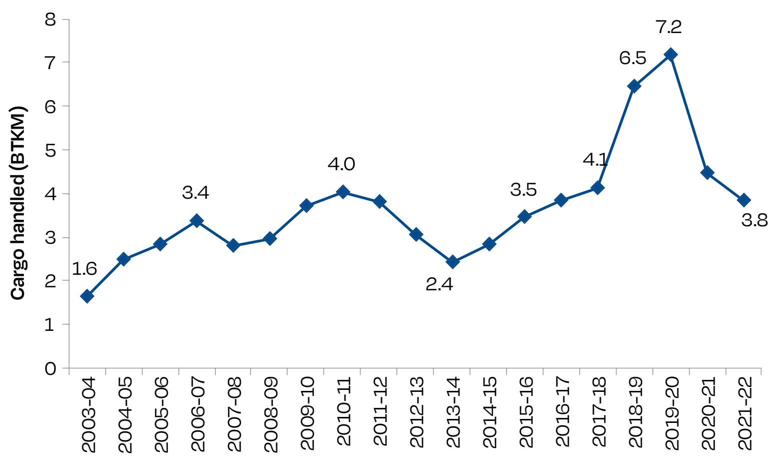
Figure 2.10: Trends in cargo handled by major and non-major ports



Source: Basic Ports Statistics of India

During April to June, 2023, the total cargo movement on national waterways was 7.8 million tonnes– a 33 percent decrease compared to the same quarter in the previous year (Figure 2.11).[13]

Figure 2.11: Cargo handled by IWT



Source: Statistics of Inland Water Transport 2021-22, IWAI

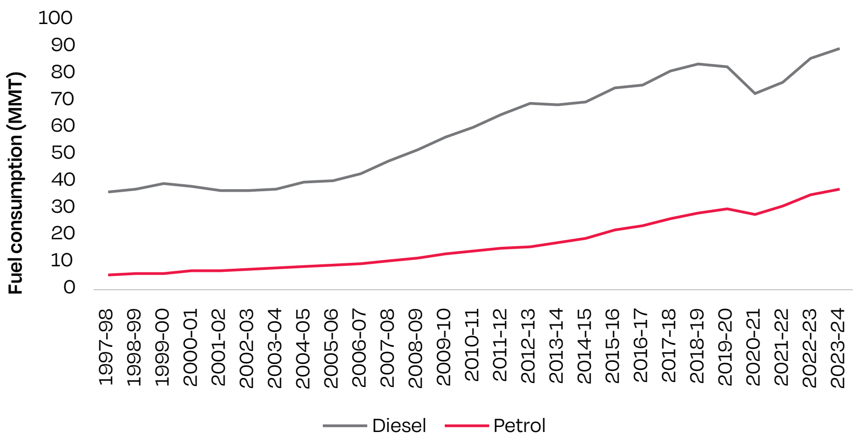
2.3 Fuel Use

India's transport is majorly constituted by the road sector, which is dominated by diesel and petrol. The total domestic consumption of petroleum products for 2023–24 was 233 million metric-tonne (MMT).[14] The total diesel consumption stood at 89.6 MMT for 2023–24. Total petrol

[13] Details available at https://www.iwai.nic.in/monthly-cargo-data
[14] Details available at https://ppac.gov.in/consumption/products-wise

consumption stood at 37.2 MMT in 2023–24. Figure 2.12 shows the trends of diesel and petrol consumption over the years. As indicated, the consumption of both the fossil-based fuels has seen an increasing trend over the years.

Figure 2.12: Total domestic diesel and petrol consumption



Source: Petroleum Planning and Analysis Cell (PPAC)

Almost 80.7 percent of diesel and more than 99 percent of petrol is consumed by the transport sector itself (PPAC, 2022), contributing to high emissions. Table 2.1 shows the disaggregation of diesel consumption by different sub-sectors as revealed by PPAC studies published in 2014 and 2022 respectively. The survey period in the former study was distributed across different periods in 2012–13 and the latter in 2020–21 respectively.[15]

Road transport consumes the highest share of diesel, with an increase observed in 2020–21 compared to 2012–13. This could be attributed to increased freight demand, thereby contributing to increased diesel consumption by trucks. Railways witnessed a decline in the consumption of diesel due to increase in electrification (Indian Railways, 2021) whereas other means of transport (including aviation and shipping) have also witnessed a rise in diesel consumption. This is most probably a result of the increased cargo movement in shipping, as well as an increase in the number of domestic and international flights. In case of petrol, almost the entire fuel was consumed by passenger transport (MoPNG, 2014; PPAC, 2022).

Table 2.1: Percentage share of diesel consumption by sub-sectors

Segment	Percent Share of Diesel (Retail + Direct)	
	2012–13	2020–21
Road	66.3	77.8
Railways	3.2	2.1
Other Transport (Aviation/Shipping)	0.5	0.8

Source: MoPNG, 2014; PPAC, 2022

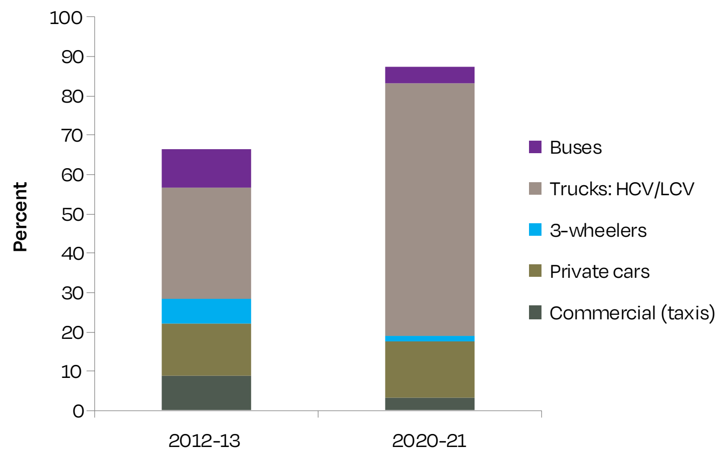
[15] The periods of the survey will be considered for the results' comparison i.e., between 2012–13 and 2020–21.

2.3.1 Road

Diesel

Figure 2.13 shows the percentage share of diesel consumed by the different segments of road transport in 2012–13 and 2020–21 (MoPNG, 2014; PPAC, 2022). The share of diesel consumption in trucks has been the highest in both years and has increased to 64.2 percent from 28.25 percent, owing to the increased demand of freight transport during the given period. About 90 percent of road freight transport (in terms of vehicle km travelled, VKT) used diesel as a fuel (Climate Group, 2022). Private cars also saw a marginal rise in the share of diesel consumed, due to a increase in the demand for SUVs. The share of diesel consumed by taxis, three-wheelers (3Ws), and buses witnessed a fall in 2020–21 as compared to 2012–13.

Figure 2.13: Percentage share of diesel consumption



Note: HCV- Heavy commercial vehicle, LCV- light commercial vehicle.

Source: MoPNG, 2014; PPAC, 2022

Petrol

Table 2.2 shows the end use share of petrol in 2012–13 and 2020–21 as revealed by PPAC (based on surveys). Two-wheelers (2Ws) dominated the total end-use consumption of petrol in both periods, with a marginally lower share in 2020–21 that could be due to price hike post COVID-19. This hike especially affected the 2W owning rural segment of the population. The next prominent segment of petrol consumption for the period 2020–21 was private cars and SUVs—higher than the combined share of privately owned cars and taxis in the period 2012–13 reflecting an increase in the ownership demand of private cars and SUVs over the years. Increased demand coupled with high fossil-based fuel prices can pave way for cleaner fuel technology adoptions. The share of 3Ws (both passenger and goods) in petrol consumption also witnessed a decline in 2020–21 with respect to 2012–13 with increased utilization of CNG in this segment (PPAC, 2022).

Table 2.2: End-use share of petrol

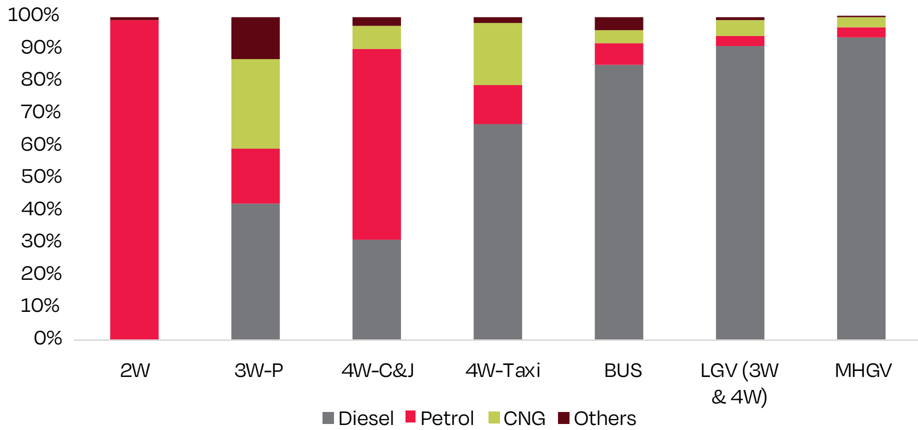
Segment	End-use Share of Petrol (%)	
	2012–13	2020–21
2W	61.4	59.0
3W-passenger	2.4	0.5
3W-goods		0.7
Private Car and SUV	35.8	36.6
Taxi		3.3

Source: MoPNG, 2014; PPAC, 2022

Compressed Natural Gas (CNG)

CNG is being massively adopted in the Indian transport segment especially in 3Ws, buses, light trucks, and cars. During 2000–05, it was found that even the first generation CNG bus technology, compliant with Euro II emission standards, resulted in a significant decline in PM emissions (about 46 times lower than diesel) and moderate NOX emissions as compared to diesel counterparts (CSE, 2010). City gas distribution organisations are required to expand CNG fuelling stations to 17,799 stations by 2030 under the Minimum Work Program (MoPNG, 2022). CNG penetration has largely been dependent on three determinants: availability of CNG fuel stations, price differential between CNG and gasoline, and consumer satisfaction.

Figure 2.14: Share of diesel, petrol, and CNG vehicles registered in cumulative terms



Note: Others include electric, LPG, hydrogen, and LNG vehicles.
Source: TERI's calculations based on VAHAN database

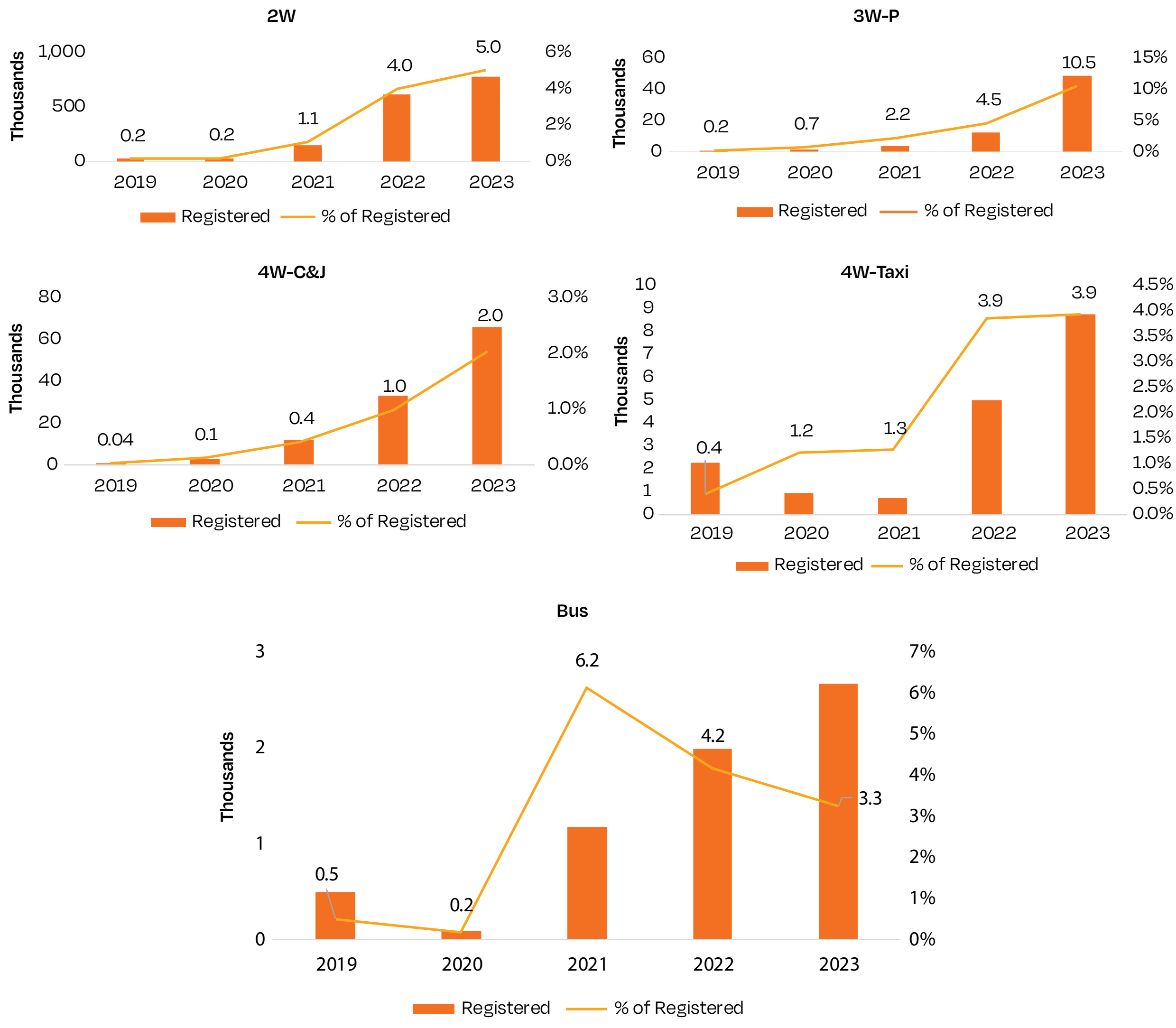
In terms of registered vehicles in cumulative terms,[16] the share of diesel, petrol, and CNG operated vehicles are shown in Figure 2.14. 2Ws are mostly dominated by petrol, with a very low share of CNG vehicles (0.02 percent) due to storage constraints as well as high cost of procurement. 3Ws (passenger) operated on CNG constitute a significant share of 28 percent although lesser than diesel-based vehicles. Privately owned cars running on CNG constitute a share of 7 percent in total registered private cars while taxis have a larger share of CNG consumption (19 percent of total registered taxis). Buses operating on CNG constitute a share of 4 percent of the total registered buses, much lesser than the share of diesel buses (85 percent). The share of CNG penetration is higher in case of light goods vehicles (LGVs) (4 percent) as compared to medium and heavy goods vehicles (MHGVs) (3 percent).

Electric vehicles

With rising transport demand and continual dependence on fossil fuels in the transport sector, the Government is pushing for increased adoption of electric vehicles to reduce the oil dependency and lower emissions. Figure 2.15 shows the registered stock of electric vehicles in the period 2019 to 2023 (in both absolute and penetration in stock terms) for various segments under passenger transport.

[16] Till November 14, 2024

Figure 2.15: Registered stock of EVs in passenger transport



Source: TERI's analysis based on Vahan database

There has been a rapid adoption of EVs in both 2Ws and passenger 3Ws, with 0.2 percent for each in 2019, to 5 percent and 10.5 percent in 2023 respectively, among the newly registered vehicles. Cost of ownership of an e-3W is lower than vehicles operating on petrol, diesel, or CNG (Harikumar et al., 2022). The case for battery swapping is expected to be favourable when it comes to taxis. The adoption of EVs in taxis has been higher than that of privately owned cars and this trend is expected to continue in future (KPMG, 2020).

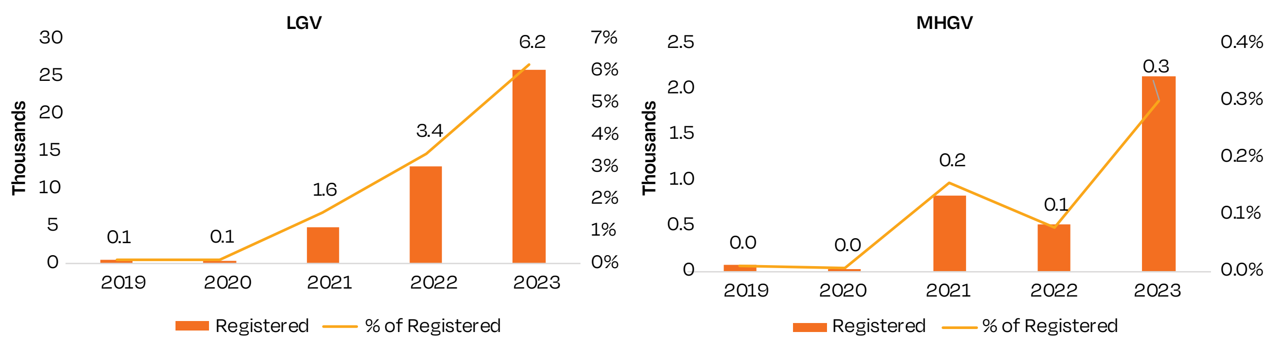
Penetration of electric buses has witnessed a fall post 2021 despite an increase in the number of e-buses being registered. Penetration in buses has been slow due to funding challenges of state corporations, making them devoid of adequate budgets for direct purchases (ITDP, 2022). India has been attempting to lower prices of e-buses through cost evenness and increased affordability, as an outcome of treating 'transportation as a service'. This has enabled producers to rent-out buses to public organizations and collect payments every month for a period of 12 years (Financial Express, 2023). However, this eventually led to stagnancy in production, with an uncertainty in returns and long-term debt burden (Financial Express, 2023). India has received aid of USD 150 million from the US government and philanthropic groups, which together with USD

240 million from Government of India creates a fund of USD 390 million. This would eliminate these risks and provide access to new investments, eventually meeting the intention of the Indian government of getting 50,000 operational e-buses by 2027 (Financial Express, 2023).

Figure 2.16 shows the EV uptake in the stock of registered goods vehicles. Electrification of LGVs (especially in 3Ws) has started to gain popularity—one of the primary reasons is the growth of online commerce. With the rising demand of online purchases, especially after the pandemic, there has been an exponential growth in demand of last-mile delivery ecosystems. Willingness of the e-commerce and logistic companies to shift to cleaner technology-based fleet is expected to increase (CSTEP, 2022) with the help of right policy ecosystem. The preference of e-LGVs supersedes over other freight categories, because of the comparatively lower cost and high level of ease of navigation across landscapes (CSTEP, 2022).

Registration of electric medium and heavy goods vehicles has increased, but the share continues to be low (0.3 percent in 2023). With soaring prices of diesel and petrol coupled with significant tailpipe emissions, the case for electrification of trucks is gaining attention (Climate Group, 2022). CNG is a popular alternative to diesel too due to low operating costs. However, methane emissions from CNG are 28–36 times more powerful than CO2, hence; any leakage can overturn the potential emission reduction (Climate Group, 2022). Other alternatives like hydrogen fuel cell could be better alternatives for freight transport, but commercial availability of the same is at a nascent stage.

Figure 2.16: Registered stock of EVs in freight transport

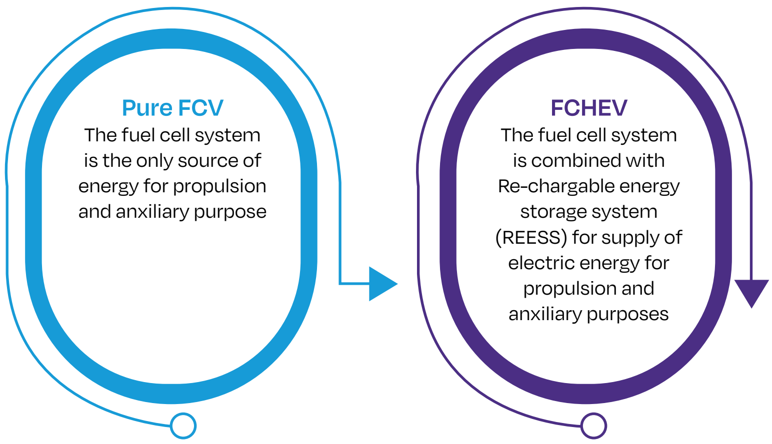


Source: TERI's analysis based on Vahan database

Hydrogen

Hydrogen as a fuel source for road transport is unavailable commercially; its scope is being discussed while tackling several constraints. For zero tailpipe emission, hydrogen fuel cell vehicles (HFCV) are one of the two alternatives, other being EVs.[17] In case of HFCVs, electricity is generated from hydrogen in fuel cells that power the electric motor, leading to zero emissions. These are more energy efficient than internal combustion engine (ICE) vehicles. Pre-dominantly, two operational modes are popular: pure Fuel Cell Vehicle (FCV) and Fuel Cell Hybrid Electric Vehicle (FCHEV). Figure 2.17 indicates the difference between the two (MoRTH, 2020).

Figure 2.17: Two primary operation modes of fuel cell vehicles in India



Source: Automotive Industry Standard, MoRTH, 2020

It is expected that upon commercialization and adoption of hydrogen fuel cell technology, it would compete with EVs in cars (private and commercial) and intra-city buses, but would be preferred over EVs in case of inter-city buses and trucks. According to Vahan portal, the total registered vehicles based on hydrogen fuel cell are only 8 in number. However, unlike FCEVs, Hydrogen Internal Combustion Engine (H-ICE) would not imply zero emissions, rather NOx emissions that would require exhaust treatment (Chabaudie, 2022). Storage of hydrogen requires high pressures which could pose concerns as in India the maximum limit that can be achieved is 350 bar, while global models have also indicated pressures up to 700 bar (Konda, 2023). Pilots with guaranteed hydrogen supply and long-term fixed prices are needed for performance checks under different conditions. Early establishment of regional hubs for hydrogen in high density passenger and freight routes would ease the refuelling needs at later stages. OEMs are working on developing fuel cell and H-ICE vehicle models.

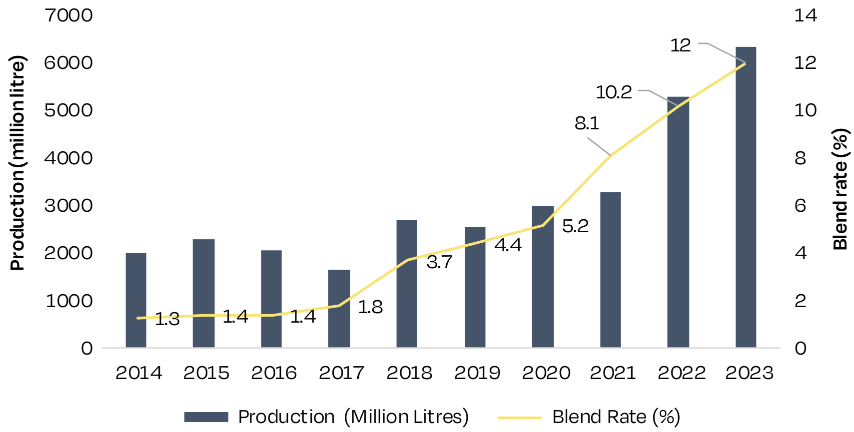
Biofuels: Ethanol blended petrol (EBP)

Biofuels are gaining momentum to address issues of fossil fuel exploitation, volatility of oil prices, import dependence, etc., due to their production, storage, transportation, and ICE-utilization ease (Sakthivel et al., 2018). Ethanol has good fuel quality, along with benefits to the environment, when blended with petrol it supplies excessive oxygen for complete combustion and leads to a decline in CO levels.[18] Figure 2.18 shows the annual fuel grade ethanol production for 2014 to 2022 and the blending rate.

[17] EVs include Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), and Plug-in Hybrid Electric Vehicles (PHEVs).

[18] Details available at https://iocl.com/green-fuel-alternatives

Figure 2.18: Production of ethanol and blending percentage



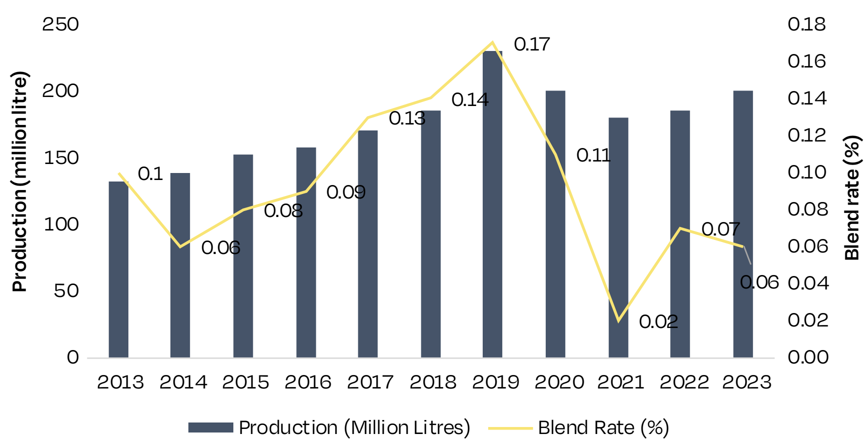
Source: USDA (2024)

At present, the commercially available petrol is blended with 12 percent of ethanol and there are plans to double this amount by 2025.[19] Under EBP, in ethanol supply year (ESY) 2022–23 the country saved more than INR 24,300 crore (1 crore = 10 million) of forex and provided benefits to farmers in the form of payments of around INR 19,300 crore (MoPNG, 2023). Decisions aimed at improving ethanol supply have resulted in significant increase in procurement by public sector oil marketing companies (OMCs), from 38 crore litres in ESY 2013–14 to 332 crore litres in 2020–21 (NITI Aayog & MoPNG, 2021). Additionally, oil PSUs are setting up second generation (2G) ethanol bio-refineries in various locations like Panipat, Bathinda, Bargrh, and Numaligarh with different production capacities (Hindu, 2023).

Biofuels: Biodiesel

Biodiesel, an alternative fuel to diesel, is produced through a simple chemical reaction involving alcohols and vegetable oils.[18] While globally, it is often derived from edible oils (such as soyabean, rapeseed, and palm oil), India prefers non-edible oil seeds from trees like Jatropha and Karanjia.[18] These trees are superior for India due to their ability to fix energy, rapid growth, and substantial yield of seeds (Jamal, 2023). The blending rate was low at 0.06 percent (USDA, 2024), a decrease from 0.07 percent in the previous year and the production was 200 million litres as shown in Figure 2.19.

Figure 2.19: Production of biodiesel and blending percentage



Source: USDA (2024)

[19] Details available at https://www.iea.org/policies/17007-roadmap-for-ethanol-blending-in-india-2020-25

Other Fuels

Other fuels in road transport include liquified petroleum gas (LPG), liquified natural gas (LNG), and hydrogen (gaseous or fuel-cell). LPG has mostly been adopted in the 3W-P segment, with more than 1 lakh (1 lakh = 100 thousand) total registered vehicles. Auto LPG is being adopted as a low carbon option to address the issue of energy security. Though LNG penetration is at a nascent stage in India, with only 169 registered goods vehicles, it is being promoted as an alternative fuel for medium- and heavy-duty vehicles, in terms of economic feasibility and environment friendliness.[20] Table 2.3 gives an overview of the feasible technologies and status of adoption of different segments in the road transport sector in India.

Table 2.3: Overview of road transport technologies: Feasibility and adoption

Fuel Type	Passenger							Freight			
	2W		3W	4W		Bus		LDV		MDV	HDV
	Motorcycle	Scooter/ Moped		Cars and Jeeps	Taxis	Urban	Inter-city	3W	4W		
Petrol	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Unlikely to be a relevant technology	Unlikely to be a relevant technology
Diesel	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists
CNG	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Technology already exists	Unlikely to be a relevant technology
LNG	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Unlikely to be a relevant technology	Technology already exists	Technology already exists	Technology already exists
Electric	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Technology already exists	Relevant with major technology advancements
Hydrogen	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Unlikely to be a relevant technology	Relevant with major technology advancements	Relevant with major technology advancements	Relevant with major technology advancements	Relevant with major technology advancements	Unlikely to be a relevant technology	Relevant with major technology advancements	Relevant with major technology advancements	Relevant with major technology advancements

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

Source: TERI

2.3.2 Railways

The primary sources of energy in case of railways are diesel and electricity. Railway has seen a significant transition to electric traction due to electrification of the Broad-Gauge (BG) network. The electrified routes entail more than 74 percent of freight traffic and more than 78 percent of passenger traffic with fuel cost on electric traction being about 47 percent of the total traction fuel cost of IR (Ministry of Railways). In 2021–22, 53.3 percent of the passenger train-km (including broad, metre, and narrow gauges) and 75.5 percent of goods train-km were powered by electric locomotives (Ministry of Railways).

Table 2.4 shows the fuel consumption of diesel and electricity for the years 2019, 2020, and 2021 for passenger and goods services. Consumption of diesel in passenger services fell in 2020 and marginally rose in 2021. Electricity consumption (per 1000 gross tonne-km, GTKM) witnessed a similar pattern, but the rise in electricity consumption has been greater in 2021 as compared to increase in diesel consumption. In goods services, there was a fall in diesel consumption in 2021, whereas electricity has seen an increasing trend.

[20] Details available at https://mopng.gov.in/en/pdc/investible-projects/oil-amp-gas-infrastructure/liquefied-natural-gas

Table 2.4: Specific fuel/energy consumption (consumption per 1,000 GTKMs)– BG

Service	2019		2020		2021	
	Diesel (KLs)	Electricity (kWh)	Diesel (KLs)	Electricity (kWh)	Diesel (KLs)	Electricity (kWh)
Passenger	3.6	18.4	3.3	15.6	3.3	21.6
Goods	1.9	6.1	1.9	7.1	1.8	7.3

Source: Ministry of Railways

Although most of the passenger and freight traffic is carried through diesel and electric locomotives, steam locomotives are still prevalent in a few closed circuits like the hill railways, mostly serving as heritage operations. Table 2.5 shows the traction-wise fleet for two periods. As of March 31, 2022, diesel locomotives constitute a share of 35.9 percent and electric locomotives constitute a share of 63.7 percent. As compared to the previous year, there has been a fall in diesel locomotives and a greater rise in electric locomotives.

Table 2.5: Traction-wise fleet

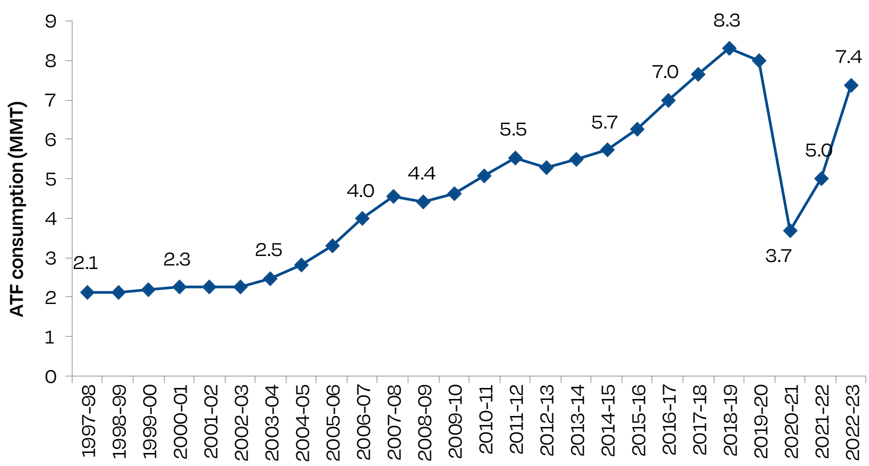
Locomotive	As on March 31, 2021	As on March 31, 2022	Percentage Change
	Traction-wise Fleet (in units)		
Steam	39	39	0
Diesel	5,108	4,747	-7.1
Electric	7,587	8,429	11.1
Total	**12,734**	**13,215**	**3.8**

Source: Ministry of Railways

2.3.3 Aviation

The aviation sector is dependent on crude oil derived Aviation Turbine Fuel (ATF) which has negative consequences towards the environment along its well-to-wheel chain.[21]

Figure 2.20: Trend of ATF consumption (domestic)



Source: PPAC

[21] Details available at https://www.teriin.org/project/sustainable-aviaton-fuel-roadmap-india

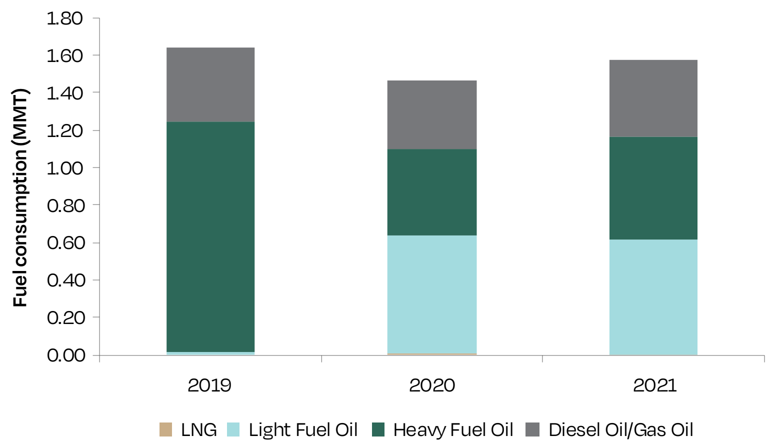
Figure 2.20 shows the consumption of ATF over the years. It has seen an overall increasing trend, with a deep fall in 2020 due to the COVID-19 pandemic. ATF consumption increased at a CAGR of 17.7 percent between 2000–01 and 2010–11 due to expansion in air transport network and dropped to 5.2 percent between 2010–11 and 2019–20. During 2022–23, 74 percent of ATF was consumed in domestic aviation, 20 percent of ATF was consumed in international aviation, and rest in military aviation (PPAC, 2023). PPAC projected that India's ATF consumption will increase from 7.39 MMT in 2022–23 to 8.61 MMT in 2023–24.

2.3.4 Waterways

Shipping

Figure 2.21 shows fuel consumption between 2019 and 2021. Heavy fuel oil dominated fuel consumption in 2019 with 1.22 MMT (about 75 percent) which decreased to 0.46 MMT (31 percent) in 2020 and increased to 0.55 MMT (35 percent) in 2021. The consumption of light fuel oil increased significantly from 0.02 MMT (only 1 percent) in 2019, to 0.63 MMT (more than 43 percent) in 2020 and a decline to 0.61 MMT (39 percent) in 2021. Diesel oil/Gas oil has continued to maintain a share in the range of 24–26 percent in 2019 to 2021. Reporting of utilization of LNG has started since 2020, with a consumption of 0.006 MMT (0.4 percent) of LNG consumed (0.4 percent) which declined to 0.002 MMT of LNG (0.1 percent) in 2021.

Figure 2.21: Fuel consumption in shipping

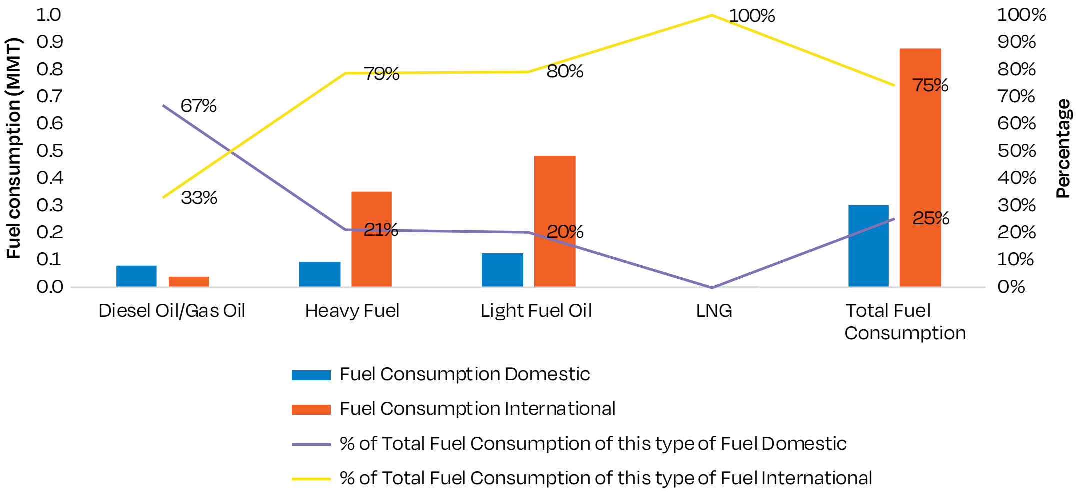


Source: Directorate General of Shipping

The Annual Fuel Consumption Report of 2021 divides ships into 3 categories: a) Category 1 ships (≥ 5000 gross tonnage, GT), not certified under River-Sea Vessel (RSV) or Indian Coastal Vessel (ICV) notification; b) Category 2 ships (≥ 5000 GT), certified in accordance with RSV or ICV notification; c) Category 3 ships (< 5000 GT) (Directorate General of Shipping).

Out of the total Category 1 ships, 113 (46.7 percent) ships are on domestic run, while 129 (53.3 percent) ships are on international run (Directorate General of Shipping). Figure 2.22 shows the fuel consumption of ships on domestic and international voyages for the year 2021. The consumption of diesel oil/gas oil was higher in case of domestic run, while the other types of fuels were consumed more in case of international runs. LNG was only used in ships operated for international voyage and not domestic. These are mostly cargo transporters on international travel (Ghosh et al., 2023). The share of total fuel consumption of Category 1 ships in international run was 74.5 percent and 25.5 percent in the domestic run. The adoption of LNG is usually argued to be limited to transition purposes (Ghosh et al., 2023). LNG has lower SOx and NOx emissions, improved cost efficiency as compared to gas oil and heavy fuel oil, and lower GHG emissions at equivalent power. However, in terms of complete life-cycle evaluation incorporating upstream and combustion emissions and unburnt methane, LNG emits 70–82 percent more GHGs than gas oil (Ghosh et al., 2023).

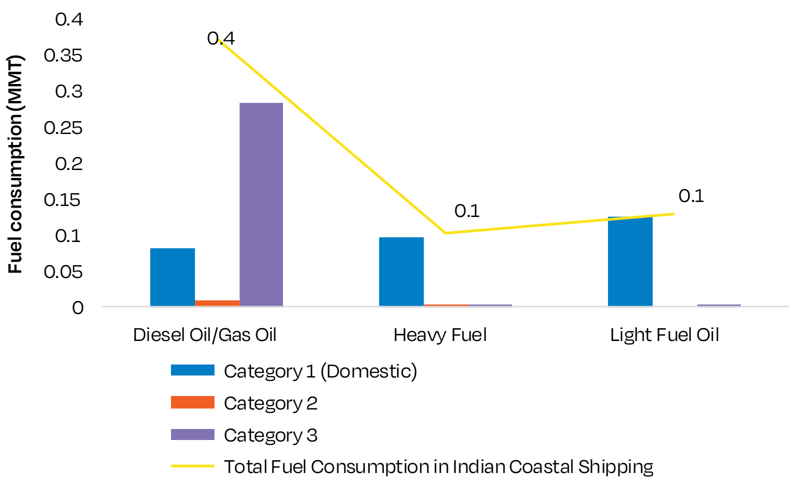
Figure 2.22: Fuel consumption of category 1 ships depending on the nature of voyage



Source: Directorate General of Shipping

Given that Category 2 and Category 3 ships are on coastal run (Directorate General of Shipping), the total fuel consumption from ships on Indian coastal waters can be estimated from summing up ships on domestic voyage from Category 1, Category 2, and Category 3. This is shown in Figure 2.23 for the year 2021, where diesel oil/gas oil was the most consumed fuel type followed by light fuel oil and then heavy fuel oil.

Figure 2.23: Fuel consumption by ships on Indian coastal waters in 2021



Source: Directorate General of Shipping

Inland Waterways

Inland water transport (IWT) is recognized to be a cost-effective, fuel-efficient, and environmentally friendly mode of transportation (RITES, 2014). For example, consider the transportation of coal in India; the carrying capacity of a 60-wagon coal train is about 1,500 tonnes of coal implying 7 trains per day for every 500 MW (IWAI). This puts a pressure on meeting the coal demand (considering existing traffic load), thus IWT can be an alternative mode of transport here. Higher fuel efficiency is observed in case of IWT, with each litre of fuel having the ability to transport one tonne of freight through 217 km by barge which is higher than the corresponding 85 km by rail and 25 km by truck (IWAI). Modal shift from road to IWT would imply savings of up to INR 2,700 crore per 10 BTKM at consumption of 3 million litre (IWAI) (with an overall diesel price of INR 89 per litre). The potential of LNG as a transportation fuel is being explored by IWAI through infrastructure development along waterways.

Alternative Fuels in Waterways

Apart from LNG, other alternative feasible fuels include biofuels like biodiesel, which is suitable for smaller vessels, electricity, methanol, and hydrogen (Ghosh et al., 2023). Ideally, fuels that are lightweight and have a low space requirement are suitable for waterways; while hydrogen fits the former characteristic, it requires space. Moreover, battery cell-based fuels are both heavy and require space (Ghosh et al., 2023). Regulations by IMO pertaining to sulphur particulates and NOx post January 1, 2020 have made the switch to cleaner fuels in water transport unavoidable and Roll on and Roll off vessels are being converted to methanol-based vessels—replacing heavy oil/bunker oil that would operate on National Waterways in IWT (NITI Aayog, 2018). Fuels like methanol and ammonia can be produced without fossil fuels, which are suitable for sectors of transportation which do not involve direct electrical propulsion like that of the shipping sector (BEE, 2022).

2.4 Energy and Emissions

During the COP26 Summit, India defined comprehensive five-point mission statement that includes a focus on increasing renewable capacity (with non-fossil power generation reaching 50 percent) and reducing energy sector's dependence on fossil fuels.[22] Amidst the global energy supply-demand challenges aggravated by the COVID-19 pandemic and the intensified geopolitical tensions, India has been actively pursuing various strategies. These include diversification of crude oil sources, investment in alternative fuel technologies such as electricity and biofuels, and building capacities for green hydrogen (MoPNG, 2023).

In the domain of global primary energy consumption, India holds the third position, constituting a share of 6.1 percent, and this share is anticipated to expand in future (MoPNG, 2022). In the primary energy mix of the country for the year 2021, coal, oil, and natural gas together contribute approximately 70 percent, and biomass contributes significantly with share of 22 percent.[23] India's heavy dependence on coal, oil, and gas in energy use makes it the third largest emitter of CO_2 (Gupta et al., 2022) despite per capita carbon emissions being lowest in the top 20 emitters in 2021 (Bhattacharya, 2022). However, in order to achieve the Paris Agreement's goal to keep the global temperature well below 2°C (close to 1.5°C), India in its nationally determined contribution (NDC) committed to reducing its emission intensity of GDP by 45 percent compared to 2005 levels (MoEFCC, 2022) by 2030.

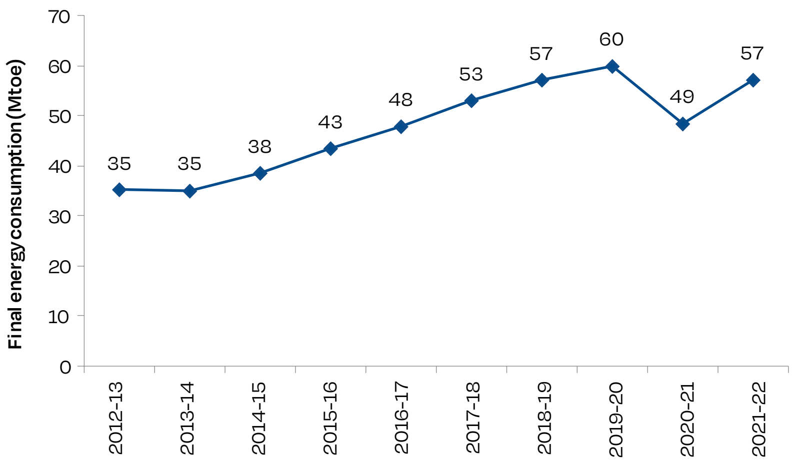
[22] Details available at https://www.mea.gov.in/Speeches-Statements.htm?dtl/34466/National+Statement+by+Prime+Minister+Shri+Narendra+Modi+at+COP26+Summit+in+Glasgow

[23] Details available at https://www.iea.org/countries/india#data-browser

2.4.1 Energy Consumption and Emissions from Indian Transport Sector

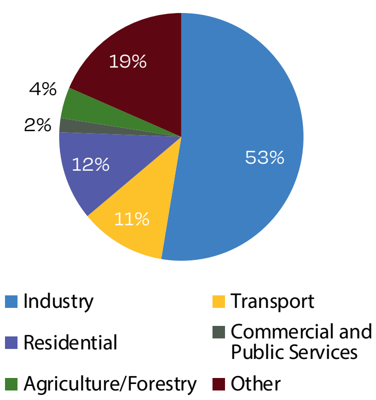
The end-use energy consumption by transport sector has grown at a CAGR of 5.6 percent for the period of 2012–13 to 2021–22 as shown in Figure 2.24 (MoSPI, 2023). Transport accounted for 11 percent of the total end-use energy consumption in 2021–22 (MoSPI, 2023), as shown in Figure 2.25 which is expected to further increase with acceleration in economic growth.

Figure 2.24: Final energy consumption of transport in India's energy balance



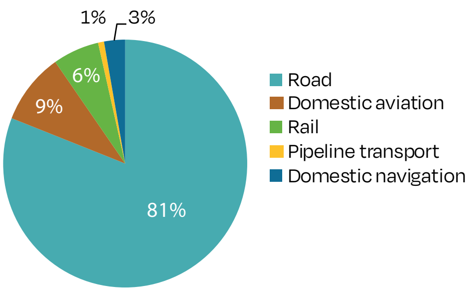
Source: MoSPI (2023)

Figure 2.25: Sector-wise distribution of India's final energy consumption



Source: MoSPI (2023)

Figure 2.26: Composition of final energy consumed by the transport sector in 2021–22



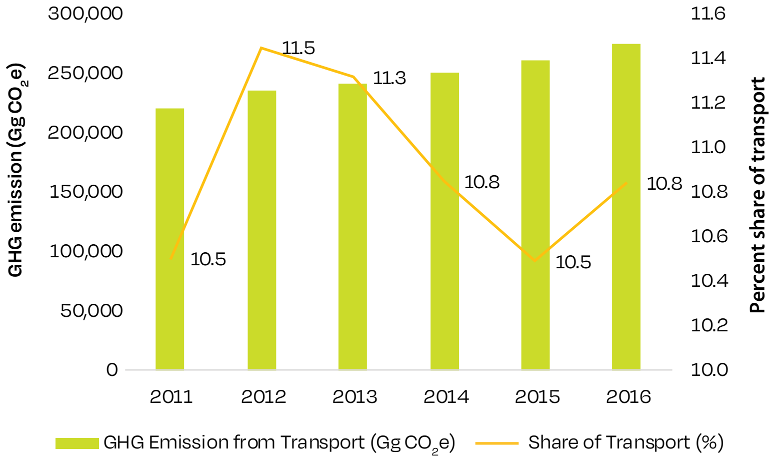
Source: MoSPI (2023)

Road transport contributes to 81 percent of the energy consumed by the transport sector followed by domestic aviation (9 percent) and then rail (6 percent) (MoSPI, 2023) as shown in Figure 2.26. Domestic aviation consumes more energy despite having lower demand than trains. Hence, railways are more energy efficient than air travel and hence, a net shift from aviation to rail, would further reduce end-use energy consumption and emissions (IEA, 2023) (indicated by Figure 2.27 as well) but this should be coupled with resolving the capacity constraints that plague the railway network to meet the required demand.

Figure 2.27 shows the GHG emissions from the transport sector over the period 2011 to 2016 (MoEFCC, 2021). There has been an increasing trend in the GHG emissions from energy in the transport sector and the share of transport in the total energy based GHG emissions has been around 10–11 percent for the period between 2011 and 2016. As shown in Figure 2.28, road transport constitutes 90 percent of the GHG emissions followed by civil aviation (6 percent), and railways (3 percent).[24]

[24] Details available at https://iced.niti.gov.in/climate-and-environment/ghg-emissions/energy

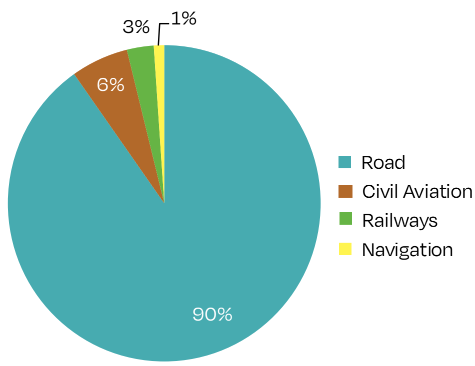
Figure 2.27: GHG emissions from transport (Gg CO_2e) and the shares in total energy-based GHG Emissions



Note: Gg CO_2e- Giga gram of CO_2 equivalent.

Source: MoEFCC (2022)

Figure 2.28: Composition of GHG emissions in transport (2016)



Source: NITI Aayog

Apart from this, waterways are more energy efficient as compared to both road and rail with value of energy consumption of 0.0048 litres/TKM compared to 0.0313 litres/TKM of road and 0.0089 litres/TKM of rail (MoPSW, 2023).

2.4.2 Alternative Technologies for Energy Transition in Transport Sector

In India, the shift toward EVs stands as a crucial component in achieving a sustainable future for transportation. Apart from its initial generation phase, the utilization efficiency of electricity in motors, generating rotary motion for various everyday purposes, can surpass 90 percent which makes electricity a crucial energy carrier for mobility (Nouni et al., 2021). In terms of mobility, hydrogen emerges as the primary contender to electricity, providing comparable advantages. Hydrogen possesses gravimetric energy content of 120.7 MJ/kg which is 2.7 times the calorific value of petrol (Nouni et al., 2021). Additionally, it is environmentally friendly, causing no emissions except for water vapour at the point of use. Nouni et al. (2021) conducted a comparison of energy delivered to the wheels, factoring in losses from various sub-systems, for a typical BEV and a FCV within the Indian electricity distribution system. The result indicated that, in terms of overall efficiency of energy utilization, a BEV (52.24 percent) is notably superior compared to an FCV (22.21 percent), however, stressed on FCVs for long-distance transport.

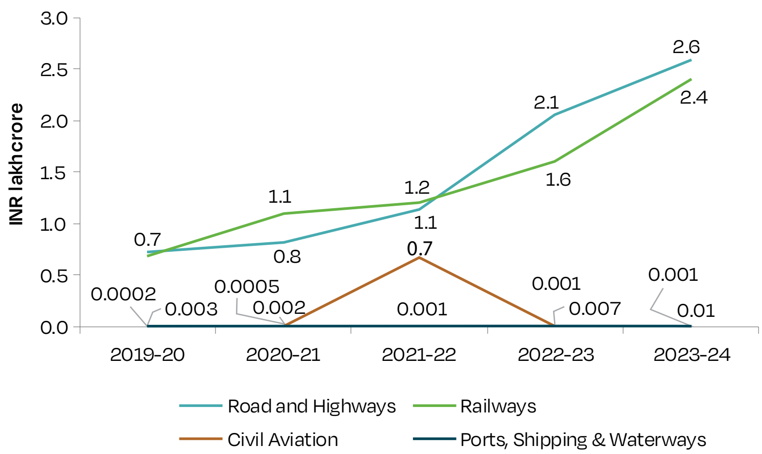
3

Policy Landscape

3.1 Infrastructure Investment

Infrastructure is significant to the growth of any economy with an estimated multiplier effect of about 2.5–3.5 times (NITI Aayog, 2021). This becomes even more important in cases of economic contractions caused by shocks like COVID-19. Targeted public investments across periods would facilitate crowding in of private investment rather than crowding out (NITI Aayog, 2021) which is important for a sector like transport where improved connectivity and enhanced facilitation of goods and passenger movement is a derived output of investment in infrastructure. With different modes of transport like road, rail, aviation, and water intertwined together, initiatives to develop multimodal transport connectivity as an asset for the economy are being undertaken extensively. PM-Gati Shakti National Masterplan, by bringing multiple Ministries under a single digital platform, maps economic zones in the multimodal transport nexus, thereby envisions to improve connectivity and bring down costs of logistics (NITI Aayog, 2021). Similarly, National Logistics Policy (NLP) launched on September 17, 2022, aims to develop the logistic sector through improvement in services, digitization, and skill enhancement and drive business competitiveness through adoption of green and sustainable logistics and freight transport (Ministry of Commerce & Industry, 2023). The targets include significant reduction in logistics costs to bring India among top 25 countries in Logistic Performance Index (Ministry of Commerce & Industry, 2023). Figure 3.1 shows the planned expenditure received to respective ministries for each mode for the period 2019–20 to 2022–23.

Figure 3.1: Capital expenditure in transport



Source: Union Budget, Ministry of Finance, Government of India[25]

3.1.1 Road

As shown in Figure 3.1, roadways have received a record high allocation of 2.59 lakh crores of capital expenditure by the government in 2023–24 with more than 50 percent of it going to National Highways Authority of India (NHAI).[26] Bharatmala Pariyojana, a key project for development of roadways, focused on development of 26,000 km of economic corridors, inter-corridors, border and international road connectivity, coastal and port road connectivity, expressways, and efficiency improvement national corridors.[27] This along with the Golden Quadrilateral launched in 2000s, flagship program that contributed significantly to 'infrastructure-investment policymaking' (Ministry of Finance, 2023), and NS-EW corridors would enable improved freight

[25] Details available at https://www.indiabudget.gov.in/

[26] Details available at https://www.indiabudget.gov.in/doc/eb/sbe86.pdf

[27] Details available at https://morth.nic.in/bharatmalaphase

transport in India. Along with this, development of rural connectivity has been a prime issue for developing economies like India. In this regard, *Pradhan Mantri Gram Sadak Yojana (PMGSY)* has completed construction of 4.8 lakh km of rural roads since 2010–11.[28]

3.1.2 Railways

As shown in Figure 3.1, railways have been allocated a capital expenditure of INR 2.4 lakh crores in 2023–24, an increase of 51 percent compared to the previous year.[29] With Indian Railways (IR) having mixed corridors, there is sharing of tracks between mail and passenger trains with that of freight trains with former given more importance, hence, the speed of freight trains is observed to be low, eventually leading to increased time-costs and reduction in competitiveness of rail in comparison to road transport. To reduce time and logistics costs, dedicated freight corridors (DFC) (eastern and western) were approved in 2008 and a trial run of one section of the western DFC (Rewari-Madar) started in 2019 (Ministry of Railways, 2021). To further reduce congestion of railways and to meet the increasing demand of freight, IR intends to expand the freight loading capacity to 3,000 MMT per annum by 2027 which would imply investments into increasing the existing 10,000 wagons per month to 14,700 wagons per month (GoI, 2022). It also suggests an investment INR 50 crore to build material handing infrastructure at sidings having more than one loading or unloading a day (400 at present) (GoI, 2022). Further, IR plans to strengthen IT infrastructure to ensure timely maintenance at an expected lumpsum amount of INR 1,000 crore (GoI, 2022).

Some other projects from the government include rail connectivity initiatives for the North-Eastern states, like Bairobi-Sairang and Capital Connectivity Project (Invest India, 2023). Moreover, introduction of domestically produced *Vande Bharat Express* shows India's dedication towards high-speed rail (PIB, 2023). Functional in 25 routes (PIB, 2023), the observed occupancy was found to be 77– 101 percent in September 2023 (Mint, 2023). Other multimodal integrity initiatives include introduction of water metro operated by Kochi Metro Rail Ltd. that operates on electric batteries, thereby promoting use of clean technology and connecting passengers across islands (MoHUA, 2022).

3.1.3 Aviation

As shown in Figure 3.1, aviation has been allocated a capital expenditure of INR 86.66 crores in 2023–24, an increase of only 0.2 percent compared to the previous year.[30] The budget of 2023–24 announced construction of 50 new airports in the country, supported by developments of heliports, water aerodromes, and landing grounds (Invest India, 2023). The Greenfield Airports (GFA) Policy of 2008 paves way for the construction of Greenfield Airports in the country after being undergone a two-step process of 'Site Clearance' and 'In Principle Approval' (MoCA, 2023a). Twenty-one new Greenfield Airports have been granted approval out of which 11 are operational with 3 being international airports (PIB, 2023; MoCA, 2023b). *UDAN*, a flagship program of Ministry of Civil Aviation, launched in April 2017 and initiated in October 2018, envisions to fulfil the desire of seamless air travel of the common masses while enhancing infrastructure and improving air connectivity of tier-II and III cities (MoCA, 2022). Under the scheme, 73 airports are operational as of January 2023 and one *UDAN* flight carries an average of 52.3 passengers (PIB, 2023).

[28] Details available at https://omms.nic.in/dbweb/Home/TimeSeries
[29] Details available at https://www.indiabudget.gov.in/doc/eb/sbe85.pdf
[30] Details available at https://www.indiabudget.gov.in/doc/eb/sbe8.pdf

3.1.4 Waterways

As shown in Figure 3.1, shipping has been allocated a capital expenditure of INR 1.1 thousand crores in 2023–24, an increase of 59 percent compared to the previous year.[31] India initiated the *Sagarmala* Program which was sanctioned on March 25, 2015. A total of 500 projects were undertaken based on themes of 'Port Modernization', 'Connectivity Enhancement', 'Port-led Industrialization', and 'Coastal Community and Development' (Ministry of Ports, Shipping & Waterways, 2020). The total infrastructure cost under this program is estimated to be INR 3.5 lakh crore (Ministry of Ports, Shipping & Waterways, 2020). Out of these, 143 projects have been completed worth INR 80.2 thousand crore and 190 projects worth INR 2.1 lakh crore are under implementation (Ministry of Ports, Shipping & Waterways, 2020).

Secondly, the Maritime India Vision (MIV) of 2030 plans to accelerate the growth of maritime sector over the next decade by identifying about 150 initiatives across 10 maritime themes (Ministry of Ports, Shipping and Waterways, 2021). The total investment under this mission ranges from 3–3.5 lakh crores across both shipping and inland waterways (Ministry of Ports, Shipping & Waterways, 2021). It emphasizes on operational efficiency improvement, port-driven industrialization and building safe and sustainable ports to address the needs of growing volume of trade and logistics costs through improved evacuation and cost-effective process (Ministry of Ports, Shipping and Waterways, 2021). Targets under MIV 2030 include having 3 major ports possessing cargo handling capacity of more than 300 million tonne per annum by 2030, increasing the share of Indian cargo transhipment handled by Indian ports from 25 percent in 2020 to more than 75 percent in 2030, reducing the average vessel turnaround time for containers from 25 hours in 2020 to less than 20 hours in 2030, increasing the average daily output of a ship from 16.5 thousand GT in 2020 to more than 30 thousand GT in 2030 (Ministry of Ports, Shipping & Waterways, 2021).

Additionally, the *Jal Marg Vikas* Project-II (*Arth Ganga*) has been initiated to promote sustainable development principles by improving transport of goods and passengers through provision of depth ranging from 2.2–3 m throughout National Waterway-1 for a minimum of 330 days in a year for easy navigation for large vessels (1,500 deadweight tonnage, DWT to 2,000 DWT). It also lays down logistics interventions like multimodal terminals, jetties, barrages, channel marking systems, etc. (IWAI, 2023).

3.2 Vehicle and Fuel Efficiency

High polluting vehicles might constitute a small share but they contribute significantly to poor air quality such as the case of trucks in India, which constitute only 3 percent of the total fleet but contribute to 34 percent of the CO2 emission and 53 percent of particulate matter (NITI Aayog & RMI, 2022).

3.2.1 National Auto Fuel Policy

National Auto Fuel Policy, implemented first across different cities in the country in a phased manner, laid down fuel efficiency standards as shown in Table 3.1.

[31] Details available at https://www.indiabudget.gov.in/doc/eb/sbe78.pdf

Table 3.1: Transition in BS norms across periods and areas covered

Year	BS Norm	Areas Covered
2000	BS-II	NCR
2001	BS-II	Expanded to Mumbai, Chennai, and Kolkata
2003	BS-II	Expanded to 7 more cities
2004	BS-II	Expanded to 2 more cities
2005	BS-III	13 cities
2005	BS-II	Entire Country
2010	BS-IV	NCR and 13 cities
2010	BS-III	Entire Country
2013–14	BS-IV	Expanded to 26 cities
2017	BS-IV	Entire Country
2018	BS-VI	NCT of Delhi
2019	BS-VI	Expanded to 10 Districts of NCR and 3 Districts/cities outside NCR
2020	BS-VI	Entire Country

Source: Ministry of Petroleum and Natural Gas (MoPNG)[32]; Ministry of Road Transport and Highways (MoRTH)[33]

The Bharat Stage (BS) norms follow the path of regulations established by the European Union which are responsible for preventing fuel efficiency losses due to oil import dependency and to limit air pollution caused by vehicles. A gradual transition to BS-VI fuel was made in a city like Delhi to curb the rising pollution since 2018, extending to cities/districts within and outside NCR and thereafter, initiated throughout the country since April 2020. This transition from BS-IV to BS-VI norms can be attributed to the slacked implementation and scope for greater reduction in emissions under the present set of norms (TERI, 2022). BS-VI fuels norms require reduction of 33 percent of air pollution caused by vehicles and reduction of NOX emissions by 25 percent in petrol and 70 percent in diesel cars (TERI, 2022).

Compared to BS-III and BS-IV norms, particulate matter (PM) emission limits are more stringent under BS-VI (Gajbhiye et al., 2023). Particle number (PN) limits are introduced for light and heavy-duty vehicles, fitted with gasoline direct injection (GDI) and compression ignition (diesel engines), which would help control emissions from new diesel LDVs and HDVs (ICCT, 2016). BS-VI implemented checks like real driving emission (RDE) and in-service conformity test (ISC) for LDVs and HDVs on vehicles manufactured since April 1, 2023 (TERI, 2023). This testing mandate on real-world driving cycles enables emissions released during certification, type approval and adherence to production to be put in the same level as that of real-world conditions (TERI, 2023). In HDVs, PM is reduced by 50 percent[34] in BS-VI compared to BS-IV (Lathia & Dadhaniya, 2018).

3.2.2 Vehicle Fuel Efficiency Programme

India finalized the first set of fuel vehicle efficiency norms for light duty passenger vehicles in 2015 known as the Corporate Average Fuel Economy (CAFÉ) norms and phase 1 was initiated in 2017-18.[35] The aim was to improve fuel efficiency Standards based on weights because fuel consumption is lower for smaller cars compared to big cars and SUVs.

[32] Details available at https://mopng.gov.in/en/refining/auto-fuel-policy
[33] Details available at https://morth.nic.in/vehicular-emission-norms
[34] In steady state test

As shown in Table 3.2, for passenger cars, CAFÉ norms are applicable on motor vehicles running on petrol, diesel, LPG, and CNG, with nine or less seats (including the driver's seat) and Gross Vehicle Weight (GVW) less than or equal to 3,500 kgs.[35]

Table 3.2: CAFÉ norms for passenger cars

CAFÉ Stage	Effective Period	Average Fuel Consumption (in litres/100 km)	Corporate Average Kerb Weight (in kg) (applies to all cars sold in a manufacturing year)
Stage 1	2017–18 to 2021–22	< 5.49	1,037
Stage 2	2022–23 onwards	< 4.77	1,082

Source: Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India

Corporate Average Fuel Consumption (CAFC) standards also accompany extra credit points for compliance with super credit points for technologies like battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and strong hybrid electric vehicles (HEVs) (Roychowdhury & Chattopadhyaya, 2021).

For heavy duty vehicles fuel efficiency norms were applicable on vehicles with GVW greater than or equal to 12 tons.35 Vehicles need to be evaluated under the constant speed fuel consumption (CSFC) protocol where trucks are driven at constant speed of 40 and 60 kmph and buses at 50 kmph and further the norms lay down safety limits on axle weights.35 CAFC standards for HDVs were based on 'per-vehicle standard' wherein each vehicle model underwent certification tests (Roychowdhury & Chattopadhyaya, 2021). Similarly, norms for Light and Medium Commercial Vehicles are established which vary based on GVW. These are shown in Table 3.3.

Table 3.3: Testing speeds under CSFC protocol

Segment	Category	GVW Range (in tonnes)	Testing Speed (km/hr)
Heavy Duty Vehicle	N3 - Rigid Vehicles	12–31 and above	40
			60
	N3- Tractor Trailer Vehicles	35.2–40.2 and above	40
			60
	M3 Vehicles	12 and above	40
			60
Light and Medium Commercial Vehicle	N2 - Goods Carrier Vehicles	3.5–7.5	50
		7.5–12	40
			60
	M2 and M3 - Passenger Carrier Vehicles	3.5–7.5	50
		7.5–12	40
			60

Source: Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India[35]

Bureau of Energy Efficiency (BEE) estimated a potential reduction of 22.97 MMT of fuel consumption by 2025 (Roychowdhury & Chattopadhyaya, 2021). Analysis of the post Stage 1 implementation resulted in almost all the car companies achieving the fuel efficiency targets of 2017–18 (Roychowdhury & Chattopadhyaya, 2021). For the year 2018, IEA suggested that new LDVs were only 9 percent above the fuel consumption target of that year and according to ICCT's estimates, the fleet are moving to achieve the 2023 targets as well (a difference of 7 percent only) (Roychowdhury & Chattopadhyaya, 2021).

[35] Details available at https://beeindia.gov.in/en/programmesenergy-efficiency-in-transport-sector/fuel-efficiency

3.3 Scrappage Policy

Released in 2021, India's Vehicle Scrappage Policy formulated fitness and emission test for commercial vehicles older than 15 years and passenger vehicles older than 20 years for which automated testing stations and vehicle scrapping provisions be set up. The policy aims to control pollution by scrapping vehicles without eligible fitness and registration, to improve fuel efficiency, and enable checks and balances on cost aspect for vehicle owners. Under the policy, the government has proposed incentives for vehicle owners to scrap old vehicles and purchase new vehicles with 5 percent discount from original equipment manufacturers (OEMs), waiver on registration fee for new vehicles, provision of scrap value worth 4–6 percent of the ex-showroom price of the new vehicle to vehicle owners, provision of refund on road tax up to 25 percent for personal vehicles and 15 percent for commercial vehicles (Paul, 2023).

3.4 Electric Mobility

Shift towards low carbon mobility in India is mostly driven by electrification of transport.

3.4.1 Electrification in Road Transport

The EV penetration in India is quite low at present with penetration in sales of passenger and goods vehicles being only 5 percent in the year 2023. Much of this electric transition is presently driven by light EVs like two and three-wheelers.[36]

The National Elelctric Mobility Mission Plan (NEMMP) 2020 was initiated in 2013 with an aim to achieve fuel security by encouraging production and consumption of hybrid and EVs. The target of the scheme was to ensure a year-on-year sales addition of 6–7 million hybrid and EVs starting from 2020[37] for two-wheeler (2W), three-wheeler (3W), four-wheeler (4W), buses, and light commercial vehicle (LCV) segments. The government is keen on pushing forward domestic technology development and production to ensure energy security and bring down the cost of purchase by the incentive amount after due fulfilment of the eligibility criteria.[37]

In February, 2016, Department of Science and Technology (DST) in collaboration with Ministry of Heavy Industries (MHI) set up a Technology Platform for Electric Mobility (TPEM) to develop products and technologies suitable to India requirements, achieve a global competitive advantage in certain technologies for electric mobility, and boost technical capability of industries to wean off the demand incentives for EVs gradually in the future.[38] In August 2018, a draft amendment to the Central Motor Vehicle Rules was released that enabled retrofitting of conventional vehicles into electric or hybrid electric based vehicles.[39]

Demand-Side Incentives: FAME-India Scheme

Under NEMMP 2020, the Faster Adoption and Manufacturing of (Hybrid&) Electric Vehicles (FAME) Scheme was launched in 2015. Two phases have till now been implemented to encourage adoption of EVs among end-users. Phase-I, from 2015 to 2019, had a total outlay of INR 895 crore out of which incentives worth INR 360 crore were given out in support of 2.8 lakh EVs (PIB, 2022). Phase-II was initiated in 2019, initially for a period of three years, and was extended for two

[36] Details available at https://www.niti.gov.in/sites/default/files/2023-02/EV_Handbook_Final_14Oct.pdf
[37] Details available at https://evyatra.beeindia.gov.in/central-govt-initiative-details/dhi-2/
[38] Details available at https://dst.gov.in/dhi-dst-technology-platform-electric-mobility-tpem
[39] Details available at https://e-amrit.niti.gov.in/national-level-policy

additional years till March 31, 2024 (MHI, 2021). Phase-II focused on subsidizing and providing demand incentives, under a total outlay of INR 10,000 crore, breakup of which is shown in Table 3.4 (MHI, 2021).

Table 3.4: Breakup of fund allocation under FAME-II scheme

Component	2019-20	2020-21	2021-22
Demand Incentives	822 (73%)	4,587 (91.7%)	3,187 (91%)
Charging Infrastructure	300 (26%)	400 (8.0%)	300 (8.6%)
Administrative Expenditure (Publicity, ICE Activities, etc.)	12 (1%)	13 (0.3%)	13 (0.4%)
Total for FAME-II	1,134	5,000	3,500

Note: Values are measures in INR crore.

Source: Ministry of Heavy Industries (MHI), 2021

Segments covered under FAME-II are shown in Table 3.5 and Table 3.6 shows the progress of the scheme as of February 2024.

Table 3.5: Segment-wise incentives under FAME-II

Vehicle Segment	Type	Maximum Number of Vehicles	Approximate Battery Size (kWh)	Approximate Incentive Granted per Vehicle (in INR lakhs) [a]	Total Fund (INR crores)
Buses	EV	7,090	250	50	3,545
Four-wheelers	EV	35,000	15	1.5	525
	Strong Hybrid	20,000	1.3	0.1	26
	Total	55,000	-	1.6	896.5
Three-wheeler (including e-rickshaws)	EV	500,000	5	0.5	2,500
Two-wheeler	EV	1,000,000	2	0.2	2,000

Note: [a] Incentive was granted at the rate of 10,000/kWh for all vehicles excluding buses and trucks for which the rate was 20,000/kWh.
Source: Ministry of Heavy Industries (MHI), 2021

Table 3.6: FAME-II progress (sales, fuel, and emission savings)

Vehicle Type	Number Sold
2W	970,027
3W	115,372
4W	14,231
Total	**1,099,630**
Fuel Saved per day (in litres)	**989,384**
CO_2 reduction per day (in kg)	**1,986,807**

Note: As of February, 2024

Most of the subsidies implied increased purchasing propensity of consumers due to lower manufacturing cost which are mostly constituted by the cost of batteries. Along with this, to further boost consumer confidence, the scheme intended to build a robust charging infrastructure with INR 800 crore being attributed to setting up of public fast charging stations (MHI, 2023).

Further, Ministry of Heavy Industries (MHI) has recently devised a scheme called the Electric Mobility Promotion Scheme, 2024 for a period of four months (April to July), with an outlay of INR 500 crores (MHI, 2024). The aim of the scheme is to boost the uptake of electric two-wheelers and electric three-wheelers (MHI, 2024).

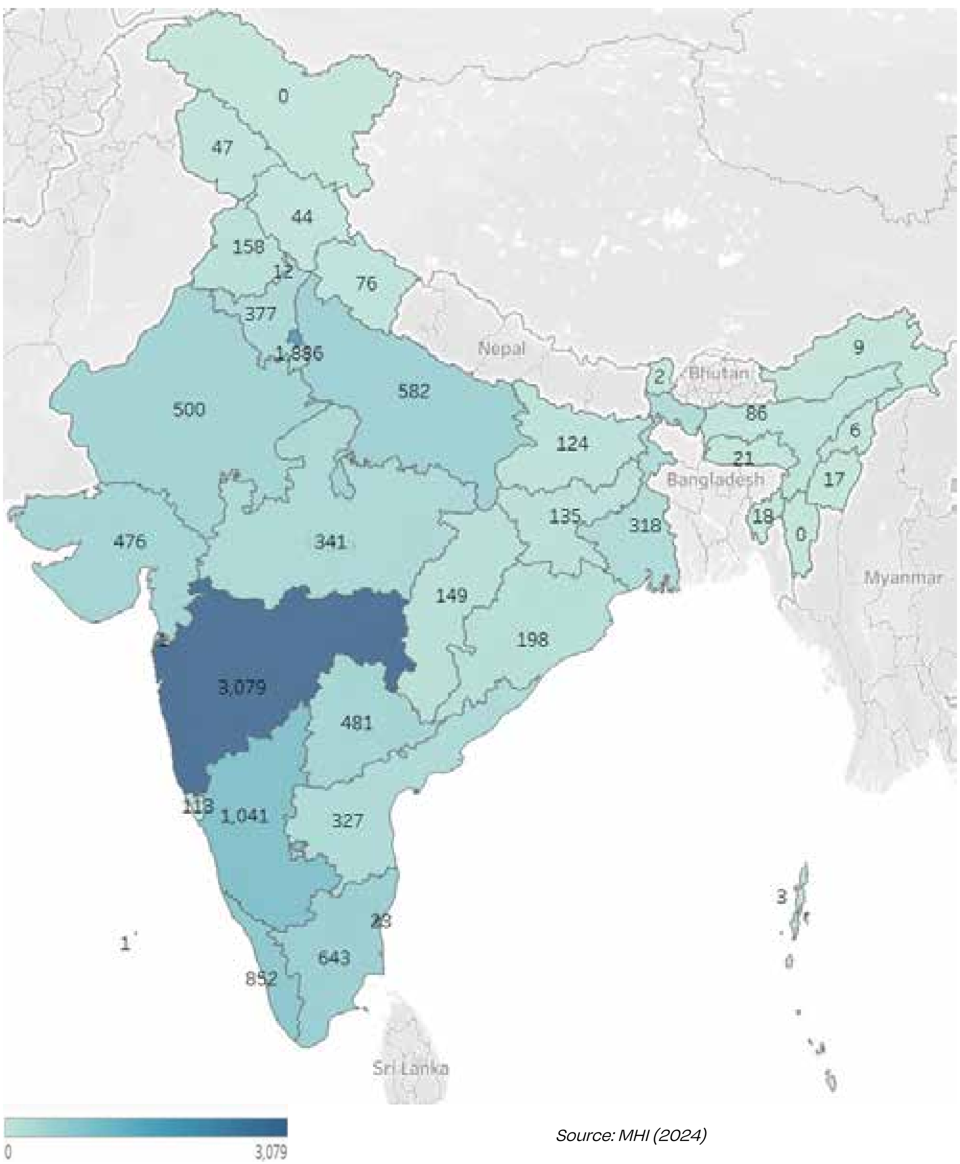
Charging Infrastructure

Development of charging infrastructure is not moving at the same pace as that of EV penetration in India. This can be attributed to low investment potential in setting up of charging stations, primarily due to high rental of land acquisition and chargers and minimum revenue earning scope (Ministry of Power, 2022).

MHI had sanctioned 520 EV Charging Stations under Fame-I Scheme out of which 479 (92.1 percent) had been installed till December 2022. FAME-II scheme intended to further boost the charging infrastructure with 800 crores being attributed to setting up of public fast charging stations. Under FAME-II, 2877 charging stations were sanctioned in 68 cities, out of which 36 had been installed by March 2022 (MHI, 2022). Additionally, 1,576 charging stations were sanctioned in 16 Highways and 9 Expressways (MHI, 2022). To facilitate electric transition for long distance travels like trucks and buses, provision of at least one fast charging station at every 100 km, on each side of the highways has been laid out (Ministry of Power, 2022). Under FAME-II Scheme, MHI sanctioned 7,432 public fast charging stations (MHI, 2023a). Norms for charging points included one fast charger (FC) per 10 electric four-wheelers (4Ws), one FC per 10 electric buses (NITI Aayog)[40] and one slow charger per each electric bus (MHI, 2019).

Figure 3.2 shows the state-wise operational public charging stations as on February 2024 (MHI, 2024). In terms of public charging station density (per 10 sq. km), Delhi has the highest density of public charging stations available, at 1.26, followed by Chandigarh at 0.1. Among the states/UTs with operational public charging stations, Arunachal Pradesh has the lowest public charging station density at 0.00011 per 10 sq. km. Though Maharashtra has the highest number of operational public charging stations, public charging station density is at 0.01, due to the vastness of the state.

Figure 3.2: State-wise operational public charging stations



Source: MHI (2024)

[40] Details available at https://www.niti.gov.in/sites/default/files/2021-08/HandbookforEVChargingInfrastructureImplementation081221.pdf

To accelerate EV transition, several incentives have been laid down to address the barriers to expansion of charging infrastructure like accessibility, cost of investment, and consumer confidence. Firstly, the Ministry of Power granted open access provision to Public Charging Stations (PCS) to all generation companies after they pay an amount equal to the level of cross-subsidy (less than or equal to 20 percent) (Ministry of Power, 2022).

Secondly, to ensure accessibility, at least one PCS is guided to be located at every 25 km on both sides of highways and at least one station located in a grid of 3X3 sq. km (Ministry of Power, 2022). Accessibility is further eased by amendments made by Ministry of Housing and Urban Affairs (MoHUA) in the 'Model Building Byelaws' (of 2016). One-fifth of the 'Vehicle holding capacity/ parking capacity' was required to be directed towards establishment of charging stations. Further, the premises of the building were required to add extra power load for simultaneous operations of all charging points (keeping in check a safety factor of 1.25) (NITI Aayog). Charging stations being established in Retail Outlets (ROs) of oil marketing companies (OMCs) are important initiatives by MHI and MoPNG to tackle land accessibility. Out of these, 76 percent of chargers are of 50/60 kWh capacity and 24 percent are of 100/120 kWh capacity (MHI, 2023).

Thirdly, on cost fronts, GST on charging stations or chargers has been brought down from 18 to 5 percent (MHI, 2023b). Additionally in the power sector, a single part tariff has been imposed on electricity supply in public EV Charging Stations– less than or equal to the 'average cost of supply' till March 31, 2025. Further, cost incurred by expansion of charging infrastructure by DISCOMS will not be borne by consumers of public EV charging stations as the funds could be leveraged from the Revamped Distribution Sector Scheme. Sixty percent of the overall cost of establishing PCS is constituted by the cost borne by charging points or operators to procure electricity from DISCOMs (relevant to upstream infrastructure), 80 percent of which has been incentivized by the MHI (MHI, 2023a).

Despite such incentives, the charging infrastructure fails to meet the supply and demand of EV transition with every public charging station[41] catering to 290 EVs.[42] Challenges like range and accessibility issues continue to persist on the demand side. The supply side is plagued with problems as central and state monitoring is inadequate. The distribution of charging stations falls behind the demand requirement. Automobile manufacturers are reluctant to shift from ICE to EVs due to low profitability now with a switch from BS-IV to BS-VI. Caps and ceilings in eligibility to avail EVs (Arthur D. Little, 2022) and procurement costs of electric buses not being leveraged through adequate finance have added on to the concerns (R et al., 2023).

The Ministry of Power is also exploring 'Time of Use Tariffs' (varying tariff rates for normal, solar, and peak hours) to incentivise solar power consumption (IEA, 2023). Growing EV density will have a negative impact on the supply-demand balance of the grid with excessive charging contributing to the peak demand of the DISCOMs. Hence, shifting EV power consumption to offload peak periods through scheduled charging is required (Sasidharan et al., 2019; Kaur & Singh, 2023).

Battery-as-a-Service (BaaS): Swapping and Leasing

In EVs, battery costs account for more than 50 percent of the total cost, hence, decoupling of battery from EVs is essential to ensure affordability of EVs (ICRIER). As a result, battery swapping[43] and battery leasing[44] are two alternatives that are usually proposed. Battery swapping is a

[41] Details available at https://evyatra.beeindia.gov.in/public-charging-stations/

[42] *Vahan* Dashboard

[43] Replacement of exhausted battery from vehicle with a new fully charged one.

[44] Monthly payments made by users on usage basis of batteries rather than owning them.

lucrative alternative for investment and has been supported by MoRTH by allowing registration and sale of EVs without batteries (MoRTH, 2020). This would enable de-linking of the battery with the vehicle; reducing the upfront cost since batteries constitute 30-40 percent of the EV cost (MoRTH, 2020). The battery in this case could be provided by the OEMs or energy service providers separately (MoRTH, 2020). The advantage of battery leasing is the reduction in the upfront cost as ownership is not required while it also poses a barrier of higher costs over life of EV (NITI Aayog). Battery swapping involves some challenges like requirement of large number of batteries for powering same number of EVs (NITI Aayog). Furthermore, Li-ion batteries dominate in India which are heavy and hence, more suitable for light-weight vehicles like 2Ws.

Supply Side Incentives: Production Linked Incentive (PLI) Scheme for Automotive Sector

The PLI Scheme for the automotive sector was approved in 2021 with a budgetary outlay of INR 25,938 crore for a period of 5 years from 2022–23 to 2026–27.[45] It was welcoming to both existing companies and new investors (MHI, 2022). Threefold objectives of the scheme are shown in Figure 3.3.

Figure 3.3: Three-fold objectives of PLI scheme for the automotive sector

Source: Ministry of Heavy Industries (MHI), Government of India[45]

[45] Details available at https://heavyindustries.gov.in/pli-scheme-automobile-and-auto-component-industry

The scheme comprises of two components: Champion OEM Incentive Scheme and Component Champion Incentive Scheme. Both are 'sales value linked' schemes (MHI, 2022). The former is applicable to Zero Emission Vehicles (ZEVs) i.e., Battery Electric Vehicles (BEVs), and Hydrogen Fuel Cell Vehicles (HFCVs) across all segments and the latter targets AAT components of vehicles, "Completely Knocked Down (CKD)/ Semi Knocked Down (SKD) kits, and Vehicle aggregates of 2W, 3W, passenger vehicles, commercial vehicles, and tractors" (MHI, 2022).

A total of 115 companies (both Indian and global i.e., from countries like Japan, USA, Germany, UK, etc.) were found to be applicants and the scheme attracted an investment of INR 74,800 crore over and above the target of INR 42,500 crore for the 5-year period (MHI, 2022). Out of this, Champion OEM Incentive Scheme attracted INR 45,016 crore and Component Champion Incentive Scheme attracted INR 29,834 crore (MHI, 2022).

PLI-ACC Scheme

Under the PLI Scheme, the National Program on Advanced Chemistry Cell (ACC) Battery Storage was approved in 2021 with a budgetary outlay of INR 18,100 crore.[46] The objective of the scheme was to build a strong foundation for 'Electric Mobility and Battery Storage' in India by establishing ACC production facilities particularly to encourage domestic outputs.[46]

The scheme requires the beneficiary firm to achieve an addition to domestic output of at least 25 percent and expand it to 60 percent in a period of five years.[46] It also requires a compulsory investment input of INR 225 crores per Gigawatt-hour (GWh) for the target capacity within 2 years.[46] The initial 2 years form the gestation period (January 1, 2023 to December 31, 2024) and the 5 years after that constitute the performance period (January 1, 2025 to December 31, 2029).[46] This initiative aims to achieve a manufacturing capacity of 50 GWh of ACC (MHI, 2022) out of which 30 GWh have been allocated to the firms.[46] The maximum incentive is kept at 20 percent of the sale price of the cell or INR 2,000 (or price quoted if lesser), whichever costs lesser per kWh (NITI Aayog & RMI India, 2022).

3.4.2 Electrification in Railways

Mission 100 percent electrification by the IR is an important step towards achieving net zero emissions. Key points of action include electrification of the entire Broad-Gauge (BG) network along with making use of renewable energy sources like solar energy for traction and non-traction purposes (Ministry of Railways, 2021). The progress of this mission has been tremendous with 82.1 percent of the total BG network of IR (including Konkan Railway Corporation Limited) being electrified by end of October in 2022 (Ministry of Railways, 2022). The Eastern Railways have achieved electrification of 85 percent of freight gross tonne km (GTKM) and 98 percent of coaching in 2020–21 (Ministry of Railways, 2021).

Benefits of electrification of traction can be reaped in the form of limiting the operations of diesel locomotive trains; curbing pollution and reducing dependence on petroleum imports. This becomes essential in case of freight transportation where GTKMs on electric traction observed a 40 percent rise in 2021 compared to 2020, despite an absolute fall in total GTKMs by 4 percent owing to COVID-19. This resulted in a fall of diesel consumption by 76 percent leading to reduced carbon intensity and foreign exchange savings (Ministry of Railways, 2021). Enhanced electrification of sidings would further boost the loading-unloading process easing out freight transportation (Ministry of Railways, 2021).

[46] Details available at https://heavyindustries.gov.in/pli-scheme-national-programme-advanced-chemistry-cell-acc-battery-storage

3.5 Alternate Fuels/Technology

According to the New Retail Fuel Policy Guidelines (2019), ROs were required to incorporate at least one new generation alternate fuel like biofuels, Liquefied Natural Gas (LNG), charging points for electric vehicles, CNG, etc. within three years of coming into operation after following due eligibilities and guidelines (MoPNG, 2020). Policy actions relevant to electrification and charging infrastructure have already been discussed above and to promote low carbon mobility and energy independence, some of the alternate fuels are being discussed in this section.

3.5.1 Biofuels

Table 3.7 shows the key biofuel blending targets prevalent in the country.

Table 3.7: Key biofuel blending targets

Key Biofuel Blended	Target Blending Percentage	Target Period
Ethanol Blended Petrol (EBP)	20	ESY 2025–26
Biodiesel	5	2030
Compressed Biogas (CBG)	Voluntary	Till FY 2024–25
	1	2025–26
	3	2026–27
	4	2027–28
	5	2028–29 onwards
SAF (only for International Flights)	1	2027
	2	2028

Source: Ministry of Petroleum and Natural Gas (MoPNG)

Ethanol Blending and Bio-Diesel

The Government had set a target of reduction of import dependence by 10 percent by 2022 from 2014–15 levels.[47] Hence, to reduce this dependence, shift to biofuels was incorporated into the transport policy framework.

National Policy on Biofuels of 2018 laid down biofuel blending targets of 20 percent of ethanol in petrol and 5 percent of biodiesel till 2030 (MoPNG, 2018). This has further been amended in 2022 with 20 percent blending of ethanol in petrol be advanced from 2030 to Ethanol Supply Year[48] (ESY) 2025-26 (MoPNG, 2022).

The roadmap for biofuel blending estimated an expected demand of ethanol in the range of 722–921 crore litres in 2025, however the recommendations proposed are laid down to meet a surplus demand of 1,016 crore litres (NITI Aayog & MoPNG, 2021). To meet the required demand, ethanol production capacity must be expanded from 684 crore litres in 2019-20 to 1,500 crore litres in 2025-26 (NITI Aayog & MoPNG, 2021). Use of E20 leads to fuel efficiency loss of: i) 6-7 percent for 4Ws designed for E0 and calibrated for E10; ii) 3-4 percent for 2Ws designed for E0 and calibrated for E10; and iii) 1-2 percent designed for E10 and calibrated for E20 (NITI Aayog & MoPNG, 2021). The Society of Indian Automobile Manufacturers (SIAM) suggested that engine modifications can minimize these losses (NITI Aayog & MoPNG, 2021). These include rolling out of E20 material compliant vehicles and E10 engine tuned vehicles (tolerance of 10-20 percent

47 Details available at https://morth.nic.in/initiatives

48 ESY is from December 1 to November 30

of ethanol blended gasoline and optimal performance under E20 fuel) from 2023 and E20 tuned engines (high performance vehicles run only on E20 fuel) from 2025 (NITI Aayog & MoPNG, 2021). The roadmap also suggests promoting diversification to water efficient crops like maize and 2G feedstock to produce ethanol (NITI Aayog & MoPNG, 2021) such that food security is not threatened.

The main aim of the policy was to make biofuels available from indigenous feedstock (GoI, 2018) to reduce import dependence. Other biofuels being explored nascently include bio-CNG wherein Municipal Solid Waste (MSW) can be converted to CNG and its applications are being researched upon especially in context of rural areas as a clean energy source (GoI, 2018). Along with this, India is a net importer of methanol. Hence, to achieve import independence in case of methanol, it is being discussed upon in transport in blended form sourced from agricultural residue, natural gas, high ash coal, etc. (GoI, 2018).

Compressed Biogas

Sustainable Alternative towards Affordable Transportation (SATAT) scheme was launched in 2018 to expand the production of compressed biogas (CBG) from biomass/waste sources like agriculture residue, cattle dung, sugarcane press mud, MSW, etc., as a transportation fuel (TERI, 2022). The scheme included establishment target of 5,000 CBG plants producing 15 million metric ton (MMT) CBG per annum by 2023–24 (MoPNG, 2022).

Government has now announced introduction of phase-wise mandates on the blending of CBG in CNG (for transport purposes) and PNG (for domestic purposes) (MoPNG, 2023). The CBG Blending Obligation (CBO) would be voluntary till 2024–25 beyond which mandatory blending would commence from 2025–26 (MoPNG, 2023). The blending percentages would be set at 1 percent, 3 percent, and 4 percent of CNG/PNG consumption for the periods of 2025–26, 2026–27, and 2027–28 respectively (MoPNG, 2023). Post that, from 2028–29, the blending target under CBO would be 5 percent. Timely implementation and monitoring would be done by a Central Repository Body (CRB) (MoPNG, 2023).

Sustainable Aviation Fuel

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was introduced as a Global Market Based Measure (GMBM) by the International Civil Aviation Organization (ICAO) in 2016 to tackle CO_2 emissions from international civil aviation. India plans to make its implementation compulsory from 2027 (TERI, 2023; MoCA, 2021).

The National Biofuels Coordination Committee has announced indicative blending targets for Sustainable Aviation Fuel (SAF) or Bio-ATF (MoPNG, 2023). Based on the potential SAF plants' capacities and projected sales of ATF, it was decided to set the target of 1 percent blending and 2 percent blending for 2027 and 2028 respectively. Both apply to international flights as of now (MoPNG, 2023).

3.5.2 Hydrogen

India's National Green Hydrogen Mission of 2023 has a production target of 5 MMT of green hydrogen annually by 2030, with a potential of production of 10 MMT annually, and an associated renewable energy capacity addition of 125 GW[49] (MNRE, 2023). Main components of production cost of green hydrogen include cost of electrolysers and renewable energy sources, and the mission aims to adopt strategies to minimize these costs for end users (MNRE, 2023).

[49] These targets are not exclusive for the purpose of transport.

Phase 1 (2022–23 to 2026–26) puts forward pilot projects for clean energy transition (fossil fuel replacement) through green hydrogen in steel production, long haul heavy-duty mobility, and shipping (MNRE, 2023). Under ports and shipping, the National Green Hydrogen Mission underlies the target of having bunkers and refuelling facilities for green ammonia (derivative of green hydrogen) at least one port by 2025 and all major ports by 2035 (MNRE, 2023) and retro-fitment or building of at least two Indian ships that would operate on green hydrogen or its derivative fuels like green ammonia or methanol by 2027, followed by an annual addition of at least two green ships each year (MoPSW, 2023).

The mission suggests that long haul mobility would require decentralization of green hydrogen production so that refuelling stations set up in cities and across highways can be connected to renewable energy plants for on-site production of green hydrogen (MNRE, 2023). The focus of Phase-1 was demand-creation and supply-enhancement by expanding domestic production capacity of electrolysers (MNRE, 2023). Phase-2 (2026–27 to 2029–30) anticipates competitiveness of green hydrogen costs with that of fossil fuels in refinery and fertilizer sectors (MNRE, 2023). Ministry of New and Renewable Energy (MNRE) has formulated guidelines for pilot projects of utilising green hydrogen in road transport (buses, trucks, and four-wheelers) in phased manner with a budgetary outlay of INR 496 crore till FY 2025–26 (MNRE, 2024). The objective is to develop hydrogen highways with supporting distribution infrastructure and refuelling stations (MNRE, 2024).

Under the purview of National Hydrogen Energy Roadmap of Government of India, the government intends to showcase and develop vehicles powered by hydrogen-based fuel cells (MoRTH, 2020). In 2020, the Automotive Industry Standard Committee (AISC) created a panel to decide upon Automotive Industry Standards for type approval of compressed hydrogen gas-based fuel cell vehicles (MoRTH, 2020). These standards identify the safety requirements relevant to performance and practice codes for hydrogen powered fuel cell vehicles (MoRTH, 2020). The objective of these standards is to minimize the damage or harm caused either due to explosive nature of the fuel in the vehicle system or high voltage induced electric shock (MoRTH, 2020). These standards are only applicable for fuel cell vehicles manufactured by OEMs and not retro-fitments (MoRTH, 2020).

However, early availability of green hydrogen is uncertain considering the high upfront costs. Supply chain security through international collaboration for fuel and raw materials needs to be strengthened where platinum utilized in fuel cell and composite cylinders for storage used under pressure in fuel cells are imported (Ministry of Science & Technology, 2022; MNRE). The fuel cell technology is at a very nascent stage and needs a swift transition and penetration like that of EVs through scaled up demand and supply incentives like that of the FAME scheme. Supply side lacks FCEVs and as conveyed by OEMs, there is no potential consumer demand for the same. However, as the famous Say's Law argues that supply creates its own demand, the government's initiatives like National Green Hydrogen Mission are steps towards production and capacity expansion. As these pace up, it is equally important to establish adequate infrastructure for distribution and refuelling.

3.5.3 Liquefied Natural Gas (LNG)

The Draft LNG Policy, 2021 paves way for use of LNG as an import substitute of liquid fuel that would imply a foreign exchange savings of 200 million USD per million tonne per annum (MoPNG, 2021). To promote LNG trucks, it has pushed forward dedicated highways with extensive LNG infrastructure like dispensing be made available across the golden quadrilateral and all major highways, industrial, and commercial centres (MoPNG, 2021). It also encourages the use of LNG as a fuel in high volume closed loop truck circuits, in areas like mining sites, refineries, etc. for increased penetration. It aims to achieve 10 percent of long-haul heavy-duty trucks and similar automotive to be LNG based by converting all those automotive to complete LNG based transmission (MoPNG, 2021). Further it also pushes for a strong regulatory environment to ensure safety and technical standards are met for storage, transport, and utilization of LNG.

The downstream initiatives include establishing 1,000 LNG stations; free sale and marketing of LNG as a fuel with freedom of any entity to establish LNG storage and distribution facility; incentivizing LNG compatible models and/or retro-fitment of long-haul heavy-duty trucks (MoPNG, 2021).

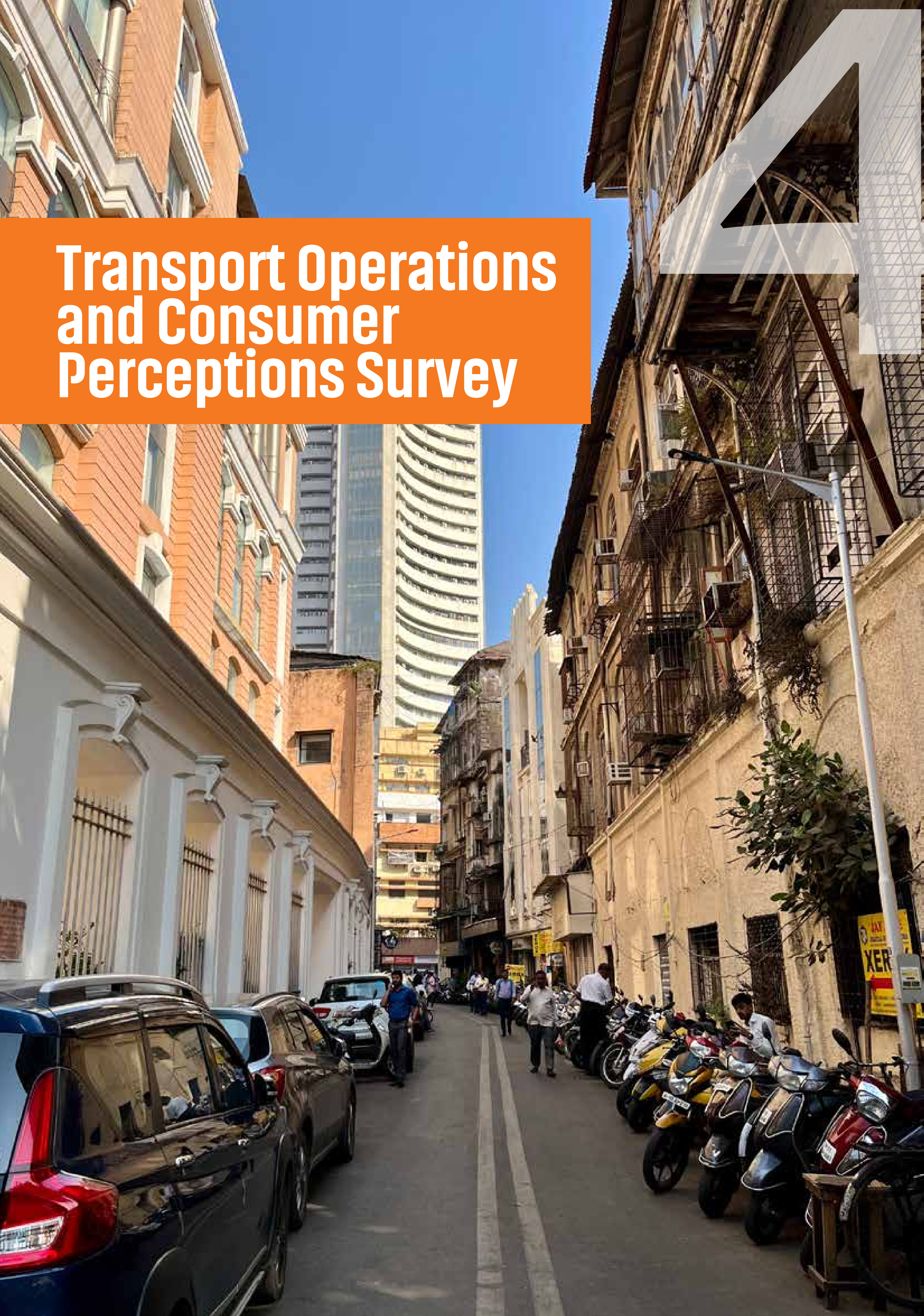
3.6 Public Transport

The National Urban Transport Policy initially framed in 2006 and updated in 2014, suggested separate allocation of road space for lanes for public transport use to get rid of costs based on traffic-based delays (MoHUA). Moreover, it encouraged subsidized fares for public transport (PT) to ensure affordability for low-income sections of population while promoting quality for high income groups from the earned revenue through subsidies (MoHUA). It also suggested exploration of alternative low carbon technologies in waterways and ropeways for hilly terrains and inclusion of trunk and feeder corridors in city plans linking to suburban traffic (MoHUA).

National Policy on Transit Oriented Development (TOD), 2017 aimed to equip mass transit stations with sustainable urban centres (MoHUA, 2022). TOD promotes both PT and NMT through infrastructure investments while increasing accessibility of the stations (MoHUA, 2022). Metro rail and Bus Rapid Transit Systems are crucial for an efficient public transport system and TOD contributes to increased ridership for same while reducing emission levels and traffic congestion (MoHUA, 2022). However, implementation of TOD has been extremely poor with major cities/ states either having no TOD policy in place or no on-ground development of TOD notifications (MoHUA, 2022).

4

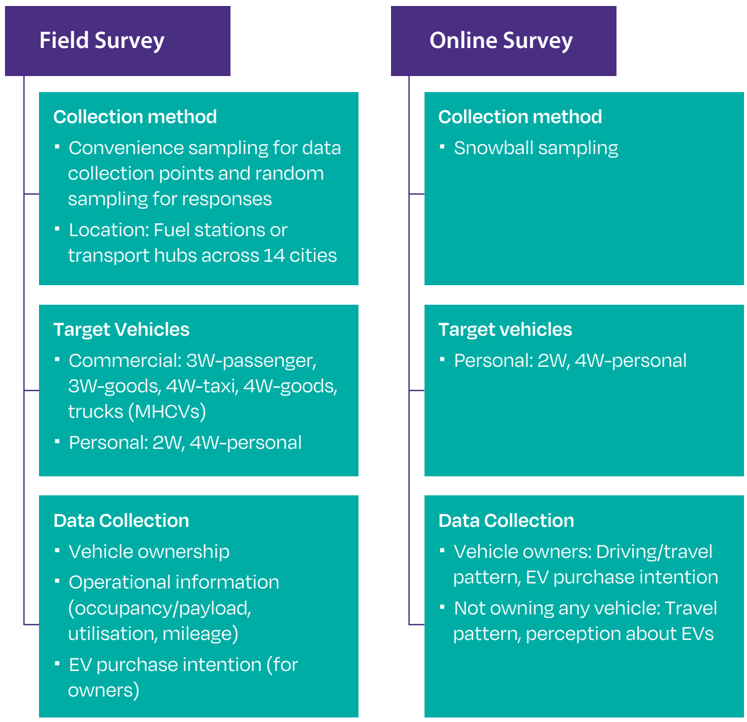
Transport Operations and Consumer Perceptions Survey



4.1 Method Overview

TERI conducted a survey to understand the operational details of different types of vehicles in the road transport sector along with perceptions on willingness to switch to electric vehicles. The data collection process was divided into two methods: (a) a pan-India field survey and (b) an online survey circulated through different social networking platforms. Figure 4.1 gives a snapshot of the two surveys conducted.

Figure 4.1: Snapshot of the methods of data collection



The field survey was divided into two categories– passenger and goods vehicle survey, to separately capture the operational characteristics of different types of vehicles. These are later used as assumptions in TERI transport model (TERI-TptM, discussed in chapter 5) to generate mode-specific outputs of transport demand, energy consumption, and GHG emissions. The surveys generated 2,056 usable responses. The responses were collected from 100 data collection points across 14 city clusters and from petrol pumps, compressed natural gas (CNG) stations, electric vehicle (EV) charging stations, transport hubs, and truck terminals.

The distribution of data collection points controls for vehicle types, geographic spread of the country, road (district, city, and village roads) and highway (national and state highways), and travel patterns (intra- and inter-city). The survey included face-to-face interviews of respondents based on pre-tested questionnaires for each category and the geo-tagged responses were fetched and recorded in a dedicated dashboard for real time updates. The field survey collected information on driving pattern of vehicle owners or drivers, operational information such as occupancy or payload, utilization, and mileage, and EV purchase intention for only the vehicle owners.

The online survey was divided into sections based on whether an individual owned and/or drove a vehicle. It was conducted in two parts– first part was similar to the field survey and collected operational details of vehicles and information about factors affecting purchase intention towards an EV from vehicle owners or drivers. The second part of the survey targeted the respondents not owning or driving a vehicle and collected information on their travel pattern, vehicle purchase intention, perceptions about EVs, and awareness about issues pertaining to transportation.

4.2 Sampling and Data Collection– Field Survey

The steps involved with data collection methodology for the field are shown in Figure 4.2.

Figure 4.2: Sampling procedure for data collection

4.2.1 Selection of States/UTs

First, the Indian landmass was divided into six distinct zones– north, south, east, west, central, and north-east. Next, 11 states and one UT were selected for survey to ensure geographical spread and to maintain inter-zonal representativeness of vehicle share. The representativeness of the data collection points and associated sample for the survey is indicated in Table 4.1. The second column indicates the percentage of vehicle population in each zone out of the total vehicle population in India, whereas the fourth column indicates the percentage of sample distribution among the selected states and UT. For example, the north zone comprises 25 percent of the total vehicle population and correspondingly, responses collected from the selected states/UTs of Delhi, Punjab, and Uttar Pradesh comprise 28 percent of the responses out of total responses in the survey.

Table 4.1: Vehicle population in the representative sample

Zones in India	Percentage in Actual Vehicle Population	Selected States/UTs in Zones	Vehicle Population in Selected State/UT in Sample (in percentage)
Central	8	Madhya Pradesh	8
East	12	Odisha, West Bengal	10
North	25	Delhi, Punjab, Uttar Pradesh	28
North-East	2	Assam	2
South	31	Karnataka, Tamil Nadu, Telangana	30
West	22	Gujarat, Maharashtra	22

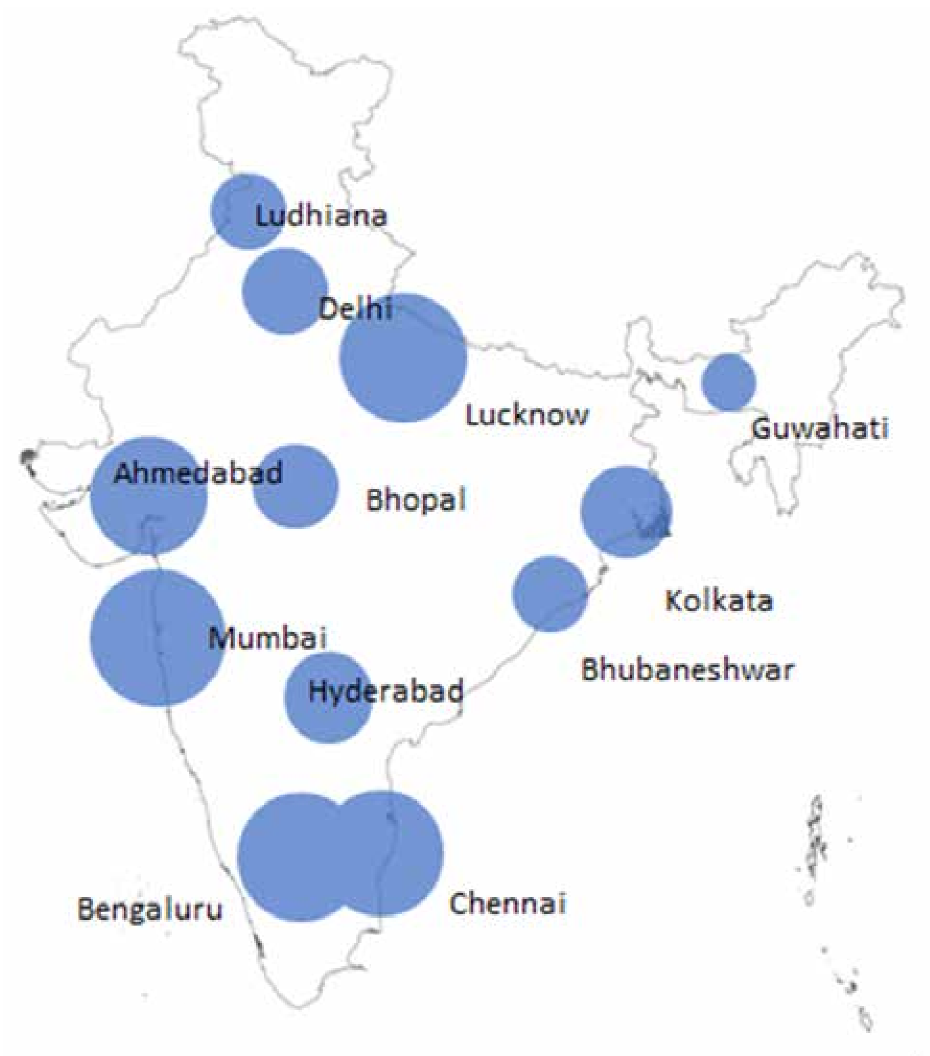
Source: TERI

To account for variations in operational pattern of vehicles (intra- and inter-city), the data collection points were further disaggregated between within city and outside city locations (located at a maximum distance of 60 km from respective city core). Based on the total vehicle population in million plus cities and total vehicle population, weights for within city and outside city data collection points were assigned to come up with the distribution of data collection points between intra and inter-city.

4.2.2 Number of Samples per Vehicle Category

The weights for data responses for each vehicle category were assigned based on the vehicle category-wise population in that city. To estimate the population-mean of desired operational attributes of the vehicles, Yamane's formula was adopted (Yamane, 1967). Based on the Yamane's formula of estimating population mean for large population with 95 percent, 400 was the minimum sample required for each of the five vehicle categories, namely– two-wheeler (2W), three-wheeler (3W, passenger and goods), four-wheeler (4W, cars, jeeps, and taxis), light goods vehicles (four-wheelers), and medium-heavy goods vehicles. Additionally, 10 percent of margin was kept as redundancy per vehicle category. The survey design thus required data collection from 2,200 respondents, distributed across 100 data collection points in India. Figure 4.3 shows the spread of data collection points across the country where size of the bubble represents the number of responses and detailed distribution is given in Annexure Table A.1.

Figure 4.3: Number of targeted responses across city clusters



4.2.3 Survey

The survey was voluntary in nature and the project team at TERI first identified the geo-locations from Google Maps and followed by development of an online application-based questionnaire for data collection. A pilot survey was conducted at Chhattarpur, Delhi on September 05, 2023 to test the quality of the questionnaire and the efficacy of the app-based survey. Minor modifications were made based on the feedback from the 15 responses (comprising two, three, and four-wheeler passenger vehicles and trucks) and the rest of the survey followed from August to October, 2023.

4.3 Survey Findings

The surveys (field and online) resulted in a total of 2,503 responses of which 2,055 were found to be usable after data cleaning. These were utilized for analysing the key operational parameters of both passenger and goods vehicles. The distribution of responses for passenger and goods vehicles is highlighted in Annexure Table A.2. For passenger vehicles, the distinction between intra- and inter-city is based on the location of the data collection points (within city and outside city, respectively) whereas for goods vehicles, that distinction is based on the most common use pattern of the vehicles as obtained in the responses.

The key operational parameters obtained from the responses are indicated in Table 4.2 and Table 4.3 respectively. Under the field survey responses, electric vehicles have not been mentioned as these constituted a negligible share in the total responses and hence, were not representative of the population of the associated vehicle type.

Table 4.2: Key operational parameters- Passenger vehicles

Vehicle Type	Fuel Type	Mileage (kmpl/kmpkg)	Passenger load factor	Daily distance travelled (km)	Observations
2W	Petrol	51	1	36	477
3W-P	Diesel	26	3.3	59	305
	Petrol	23			
	CNG	28			
	LPG	23			
4W-C&J	Diesel	17	2.7	50	662
	Petrol	19			
	CNG	22			
4W-Taxi	Diesel	18	3	175	33
	Petrol	22			
	CNG	24			

Source: TERI

Table 4.3: Key operational parameters - Goods vehicles (only based on field survey)

Parameters	LGV (≤7.5 tonnes)		MGV (>7.5 and ≤12 tonnes)		HGV (>12 and ≤16.2 tonnes)		HGV (>16.2 and ≤25 tonnes)		HGV (>25 tonnes)	
	CNG	Diesel	CNG	Diesel	CNG	Diesel	CNG	Diesel	CNG	Diesel
Payload/ trip (factoring out empty return (tonne)	1	2	2	6	10	10	10	13	28	19
Mileage (kmpl/ kmpkg)	18	15	10	9	9	6	10	4	9	4
Daily/ Annual km driven*	74	71	41,257	37,227	49,828	42,208	51,429	62,199	36,838	64,906
Total observations	414		60		53		82		128	

*Note: *Daily km in case of LGV and for all other, annual km.*

Source: TERI

4.3.1 Operational Characteristics– Passenger Vehicles

For 2Ws, the average daily distance was highest in case of motorcycles followed by scooters and then mopeds which was in tandem with the trip length for inter-city travel, but it was the highest for mopeds in case of intra-city travel. For private cars and jeeps, the average daily distance travelled was 59 km for inter-city travel and 48 km for intra-city travel. In case of passenger 3Ws, average daily distance travelled was greater than 60 km for inter-city and greater than 70 km for intra-city travel. Taxis were utilized for longer trips (an average of 60 km and 63 km for inter and intra-city respectively) implying a corresponding high daily distance travelled of around 164 km and 188 km respectively. The passenger occupancy for 2Ws ranged from 1–2 for inter-city travel and 1 for intra-city travel. For private cars and jeeps, this ranged from 2 to 3 for intra-city travel and around 3 for inter-city travel. In case of passenger 3Ws, the average occupancy was found to be 4 for inter-city travel and 3 for intra-city travel. Taxis reported an average occupancy of 3 passengers for both inter and intra-city travel. Values for mileage are also summarized in Table 4.2 and vary depending on vehicle type and fuel category.

The refuelling pattern suggested that 83 percent 2W owners/drivers, 58 percent 3W owners/ drivers, and 60 percent 4W owners/drivers currently opt for incremental refuelling (less than full tank/battery), therefore, range anxiety with the EV models may be more of a notional constraint for EV adoption than its practical impact on daily commute requirements.

4.3.2 Operational Characteristics– Goods Vehicles

On an average, for LGVs (including 3W goods vehicles), the daily distance driven was higher in case of inter-city i.e., 82 km as compared to 64 km in intra-city travel. For MGVs, the annual distance driven was 41,134 km for inter-city travel and 28,784 km for intra-city travel. In case of HGVs, on an average (weighted[50]),the annual distance driven was close to 63,000 km for inter-city travel and 38,000 km for intra-city travel. The payload carried per trip for LGVs was found to be 2 tonnes for inter-city travel and 1 tonne for intra-city travel; for MGVs, it was found to be 8 tonnes for inter-city travel and 6 tonnes for intra-city travel; and for HGVs, on an average (weighted), it was found to be 21 tonnes for inter-city travel and 17 tonnes for intra-city travel. The reported

[50] For HGVs, weighted average for different GVW ranges has been mentioned wherein the weights are based the number of responses for each GVW range as mentioned in Table 4.6.

percentage of empty return were 27 percent and 30 percent for inter and intra-city respectively for LGVs. MGVs reported this number on a lower side with 25 percent and 18 percent respectively for inter and intra-city respectively. On an average (weighted), HGVs reported an empty return of 26 percent and 27 percent for inter and intra-city respectively. The corresponding adjustments to payload carried per trip after factoring in percentage for empty return for each category has been mentioned in Table 4.3 along with values for mileage which vary depending on vehicle type and fuel category.

Among the respondents, 41 percent were owners of vehicles, 57 percent were salaried drivers, and 2 percent used vehicles on rent. The average age of the respondents was 37 years and 100 percent were male. In the goods vehicles, diesel was the major fuel in vehicles i.e., 87 percent, followed by CNG in 12 percent vehicles, and rest were LPG, electric, and LNG. 51 percent respondents opt for full tank refuelling to avoid inconvenience on long haul routes.

4.3.3 Perceptions about Electric Vehicles

Table 4.4: EV purchase intention across different vehicle segments (in percentage)

	Yes	Not Sure	No
Passenger Transport			
2W	75	15	10
3W-Passenger	80	7	13
4W (Cars, Jeeps, Taxis)	57	20	23
Goods Vehicle			
3W-Goods	75	17	8
LGV (≤7.5 tonne)	71	13	16
MGV (>7.5 and ≤12 tonnes)	50	21	29
HGV (>12 tonnes)	50	25	25

Source: TERI

EV Purchase Intention– Passenger Transport

47 percent of the total respondents expressed intention to purchase a new vehicle within next two years, out of which 78 percent were willing to purchase an EV (Table 4.4) Within the 4W category given the number of models in the market, 62 percent of the EV purchase intention was in the hatchback category, 24 percent in sedan category, and 14 percent in SUV category. The major three factors (not rank-wise) common among the passenger segments users that would enable EV purchase were– (i) long term cost advantage in terms of total cost of ownership (TCO), (ii) less probability of breaking down compared to internal combustion engine (ICE) vehicle, and (iii) incentives (demand purchase subsidy, reduced road tax and parking fee). Within the sample, EVs having an environmental advantage with no tailpipe emission was not among the major three factors which drove the purchase intention. The major concerns that would deter the EV purchase intention were– (i) high battery replacement cost, (ii) high on-road price, (iii) lack of charging infrastructure, and (iv) long charging time. Further, 4W owners/drivers were also concerned about driving performance of EVs.

Figure 4.4: EV purchase intention according to age groups

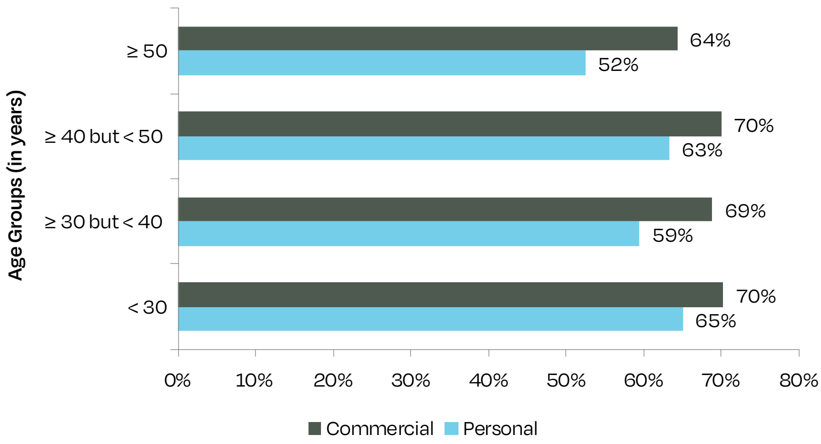


Figure 4.4 shows the EV purchase intention of respondents according to different age groups. For example, in case of personal passenger vehicles, that include 2W and 4W, 65 percent of the surveyed respondents aged less than 30 years were willing to purchase an EV. In case of commercial passenger vehicles, that include 3W-P and 4W-Taxis, 70 percent of the respondents aged less than 30 years were willing to purchase an EV.

Figure 4.5: EV purchase intention according to monthly income

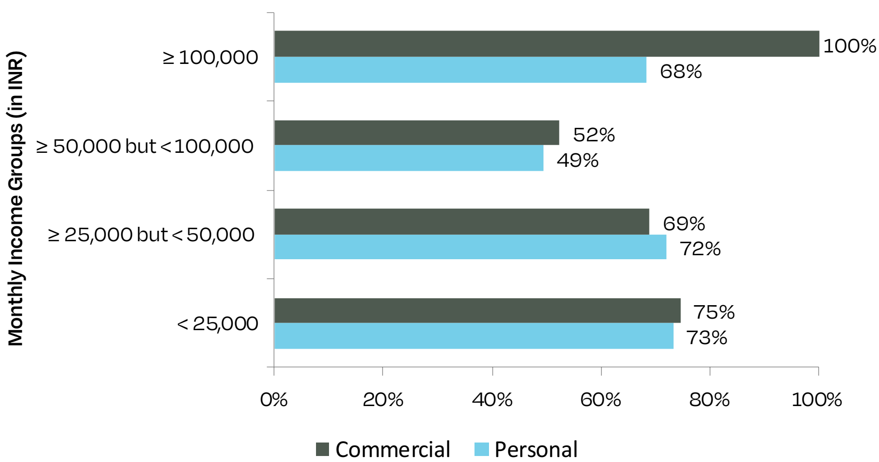


Figure 4.5 shows the EV purchase intention of respondents according to different monthly income categories. For example, similarly in case of personal passenger vehicles, 73 percent of the surveyed respondents with monthly income less than INR 25,000 were willing to purchase an EV. In case of commercial passenger vehicles, 75 percent of the respondents surveyed with monthly income less than INR 25,000 were willing to purchase an EV.

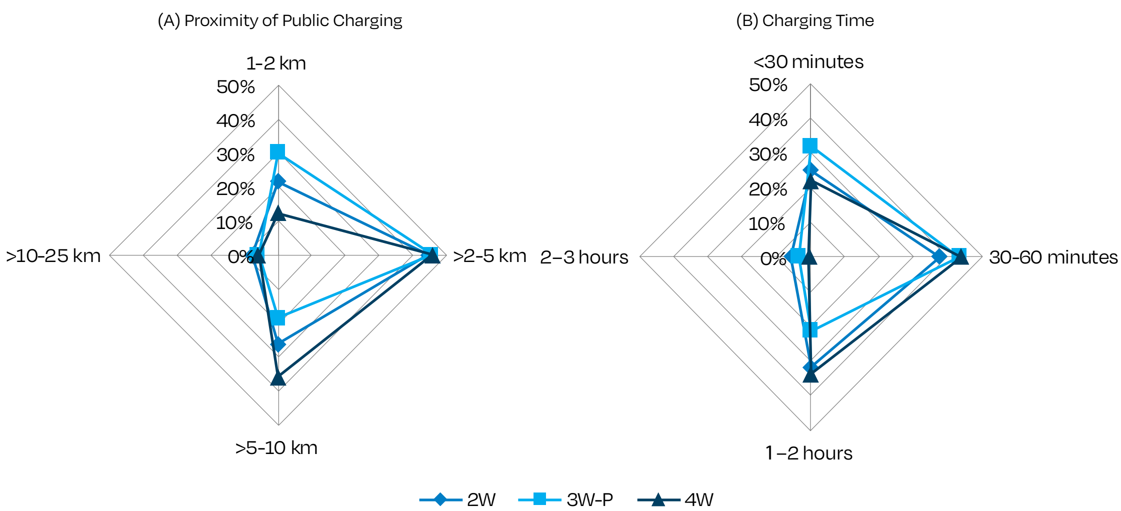
Charging Preference for Respondents Interested in EV Purchase

As far as the access to dedicated overnight parking is concerned, 80 percent 2W respondents, 97 percent 3W respondents, and 92 percent 4W respondents who wish to purchase an EV already have access to dedicated overnight parking, which could cater to their in-house charging requirements.

For assessing the desired density of charging infrastructure for accelerated electrification of road, the range preference of users for a public charging station was surveyed as shown in

Figure 4.6. The 3W drivers/owners desired non-disruptions to their daily operations such that 76 percent preferred location of public charging stations within proximity of <5 km radius and 75 percent preferred charging time of less than 1 hour. Whereas, more than 70 percent of 2W and 4W owners/drivers were comfortable with public charging station within 2–10 km proximity and charging time between 0.5–2 hours. The refuelling pattern indicates that majority of the respondents opted for incremental refuelling, which was reflected in preference for charging time lesser than full battery.

Figure 4.6: Charging preference of different passenger transport segments

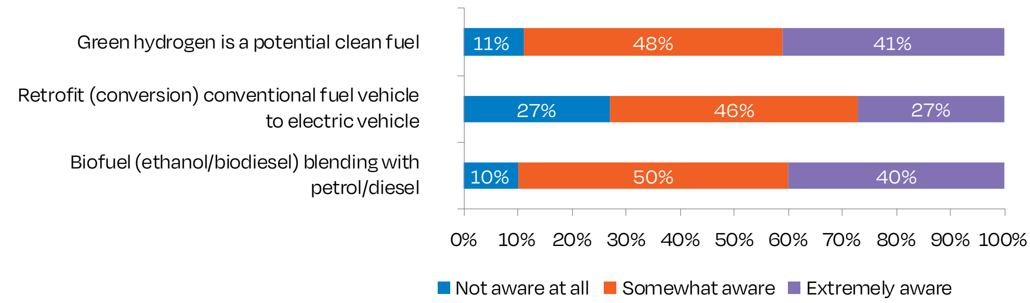


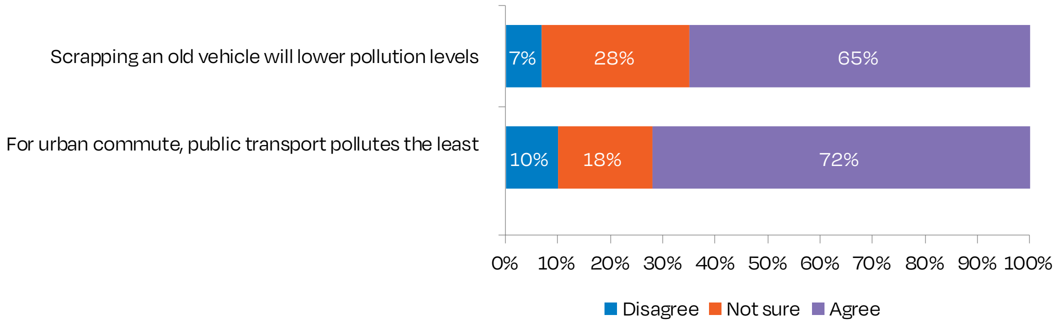
Awareness about Other Low Carbon Transport

Awareness about biofuel (ethanol/biodiesel) blending with petrol/diesel and potential of green hydrogen as a clean fuel was high with 40 percent respondents being extremely aware and only 10 percent were not aware at all about these two low carbon fuels. Comparatively, awareness about retrofitment or possibilities of conversion of existing ICE vehicle to EV was low, as the lack of knowledge was reflected by the fact that 27 percent respondents were not aware at all and only 27 percent of the respondents were extremely aware about retrofitment.

Most respondents, i.e., 72 percent agreed that public transport is a low polluting mode for urban commute and 65 percent agreed that scrappage of old and polluting vehicles will reduce local air pollution.

Figure 4.7: Awareness about low carbon transport





EV Purchase Intention– Goods Transport

Among the respondents with EV purchase intention, 63 percent were vehicle owners and 37 percent were salaried drivers. For different goods vehicle segments the purchase intention was as shown in Table 4.5. The common parameters in favour of EV purchase were– (i) long-term cost advantage in terms of TCO, (ii) incentives such as demand purchase subsidy, reduced road tax, and parking fee, and (iii) better drive experience. The common concerns were– (i) high on-road price, (ii) doubt over driving performance of EVs (speed, acceleration, power), and (iii) high battery replacement cost. Table 4.5 shows enablers and deterrents for EV purchase among the different goods vehicle segments.

Table 4.5: Segment wise goods vehicles: Enablers and deterrents for EV purchase

Vehicle Segment	Enablers			Deterrents		
LGV (≤7.5 tonnes	Long-term cost advantage in terms of TCO	Incentives	Less probability of breaking down compared to ICE trucks	Lack of charging infrastructure and long charging time	Doubt over driving performance of EVs	High battery replacement cost
MGV (>7.5 and ≤12 tonnes)	Long term cost advantage in terms of TCO	Incentives	Better drive/ride experience	High battery replacement cost	High on-road price	Doubt over servicing of EVs
HGV (>12 tonnes)	Long-term cost advantage in terms of TCO	Incentives	Less probability of breaking down	Lack of charging infrastructure	Long charging time	High on-road price

5

Transport Demand, Energy Requirements, and GHG Emissions: Baseline Scenario

This chapter first discusses the TERI Transport Model (henceforth, TERI-TptM) in details followed by the analysis of the baseline scenario for the Indian transport sector. Under the baseline scenario, transport demand, energy requirements, fuel consumption, and greenhouse gas (GHG) emissions are estimated. Two main assumptions in the modelling exercise are: (i) the selection of a suitable base year for data and (ii) timeframe for forecasting.

Base Year: The years 2020–21 and 2021–22 were marred by the COVID-19 pandemic and associated disruptions in economic activities, global supply chain, and overall transport demand. So, 2019–20 has been considered as the baseline year for modelling.

Timeframe: The timeframe for analysis spans 1990–91 to 2070–71. The projections for 2020–21 to 2060–61 are classified under four phases: (a) near-term (2020–21 to 2030–31), (b) medium-term (2030–31 to 2040–41), (c) distant (2040–41 to 2050–51), and (d) vague (2050–51 to 2070–71). It is imperative to note that the projections beyond 2050–51 may not be reliable due to future technological advancements in the transportation sector that may impact the technology in use completely. For India, long-term real GDP forecast is only available from OECD till 2060–61, additionally, for the decade between 2060–61 and 2070–71 the forecasted growth rate based on annual growth rate during 2050–51 and 2060–61 is considered. Table 5.1 lists the major parameters and respective sources.

Table 5.1: Variables and sources

Parameters	Sources
GDP (1990–91 to 2021–22)* at constant prices	National Accounts Statistics, Ministry of Statistics and Programme Implementation (MoSPI)
Real GDP growth (2022–23 to 2060–61)	OECD Real GDP Long-term Baseline Projections
Population (1990–91 to 2070–71)	UN Department of Economic and Social Affairs, Population Division (2023)
Road transport- Cumulative number of registered vehicles	Road Transport Yearbooks, Ministry of Road Transport and Highways (MoRTH)
Road transport- operational characteristics of buses	State Transport Undertakings Profile & Performance (2019-20), Central Institute of Road Transport
Indian Railways- Passenger kms (PKM), tonne kms (TKM), fuel consumption, traction shares	Annual Statistical Statements, Ministry of Railways (MoR)
Delhi Metro- Daily passengers, average lead, electricity consumption	Delhi Metro Rail Corporation (DMRC)
Aviation- PKM, TKM, occupancy, load factor,	Aviation Data and Statistics, Directorate General of Civil Aviation (DGCA)
Shipping- Tonnage, fuel consumption#	Ministry of Ports, Shipping and Waterways (MoPSW)

*Note: *Converted to 2011–12 base prices; #Data partially available and is noisy.*

5.1 Nomenclature of the Model

TERI-TptM is a bottom-up approach to estimate transport demand. It first estimates the total transport demand, followed by estimations of the energy consumption and GHG emissions (measured by CO_2 equivalent emissions). These can influence policy choices in terms of future reduction in emission from transport sector towards low carbon pathways. The conceptual framework is based on the ASIF-method (Schipper and Marie-Lilliu, 1999) represented by equation 1.

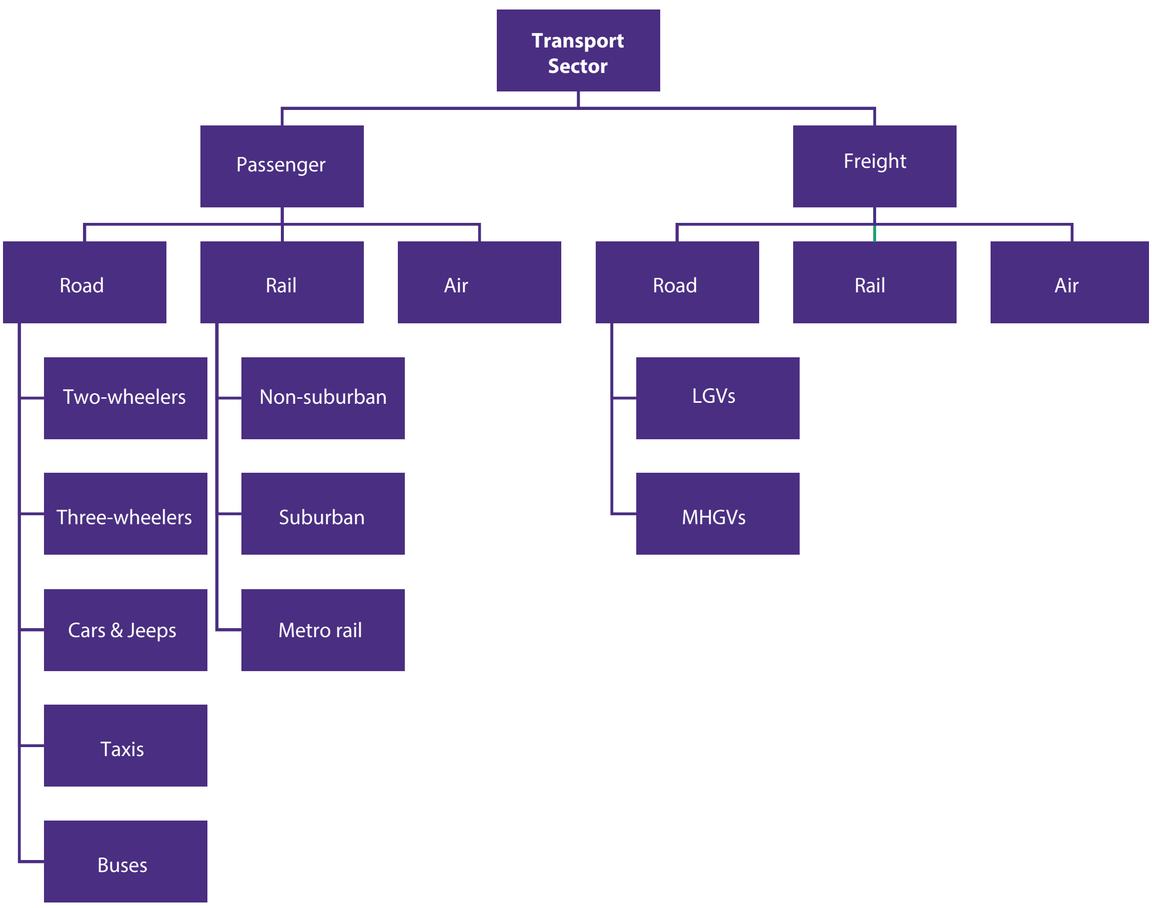
$$G = \sum_m \sum_f (A_{m,f} \times S_{m,f} \times I_{m,f} \times F_f) \quad (1)$$

Where,

G = Total GHG emission from transport sector, m = mode of transport, f = fuel type, *A* = transport **activity** in vehicle-km (VKM), *S* = mode **structure** variable representing modal share (passenger) or load-factor (freight), *I* = energy **intensity** (energy per VKM) for each fuel and mode, *F* = emission **factor** of fuel type.

Under the modelling framework, the transport sector is disaggregated primarily into two segments, namely passenger and freight.[51] Each of these segments is further disaggregated into road, rail, and air transport. Though an attempt was made to integrate shipping (coastal shipping) into the model, it was not possible owing to the unavailability of reliable historical data for estimation (a short-term assessment of coastal shipping can be found in chapter 7). Introduction of multiple sub-classes of vehicles/mode types (for roadways and railways) incorporate further granularity in the transport demand analysis (Figure 5.1).

Figure 5.1: Segmentation of transport sector in TERI-TptM

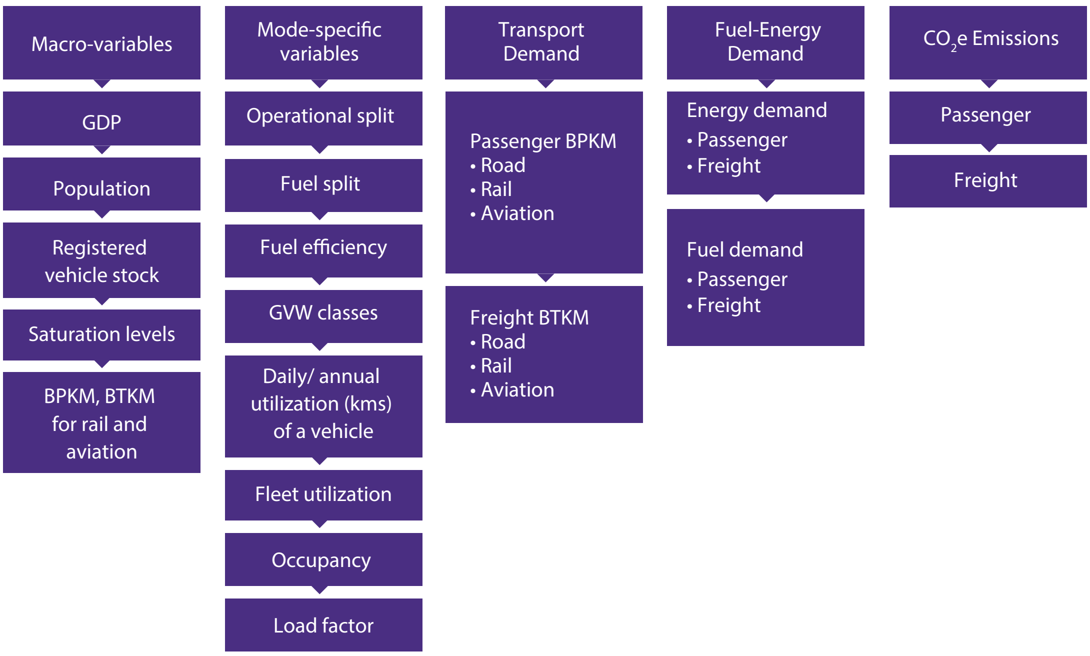


Note: LGVs- Light goods vehicles (gross vehicle weight, GVW not exceeding 7.5 tonnes), MHGVs- Medium and heavy goods vehicles (GVW above 7.5 tonnes).

[51] Only revenue earning freight has been considered in the modelling exercise.

TERI-TptM adopts a demand driven approach, wherein socio-economic variables such as GDP and population are used to estimate the transport demand. The model first estimates total transport demand in India, which is an aggregation of the projected passenger and freight demand, defined as annual Billion Passenger Kilometres (BPKM) and Billion Tonne Kilometres (BTKM), respectively. After estimating the total passenger (BPKM) and freight (BTKM) demands, total energy consumption is calculated based on assumptions on vehicle technology and fuel-split. Well-to-wheel (WTW) emission coefficients (CO_2 equivalent) are then used to arrive at the final emissions. Figure 5.2 provides a schematic of the TERI-TptM.

Figure 5.2: Structure of the TERI-TptM



Key inputs: GDP and population, billion passenger-km (BPKM) and billion tonne-km (BTKM, for rail and aviation), number of registered vehicles (for road transport), saturation levels (for different vehicle segments, it is the maximum vehicle density or level of transport activity for the country), fuel efficiencies of various technologies (and annual rates of improvements), fuel-split among different types of vehicles, occupancy rate (or the load factor for freight vehicles), vehicle utilization rate (kms driven), and emission factors of different transportation fuels (including electricity).

Key outputs: Projected passenger and freight transport demand, requirements of fuel by the transport sector, energy consumption, and GHG emissions.

Under the TERI-TptM framework, GHG emissions for road transport modes can be described by equation 2.

$$G_m = \sum_f \left(V_{m,f} \times U_{m,f} \times D_{m,f}\right) \times \left(\frac{1}{M_{m,f}}\right) \times EF_f \qquad (2)$$

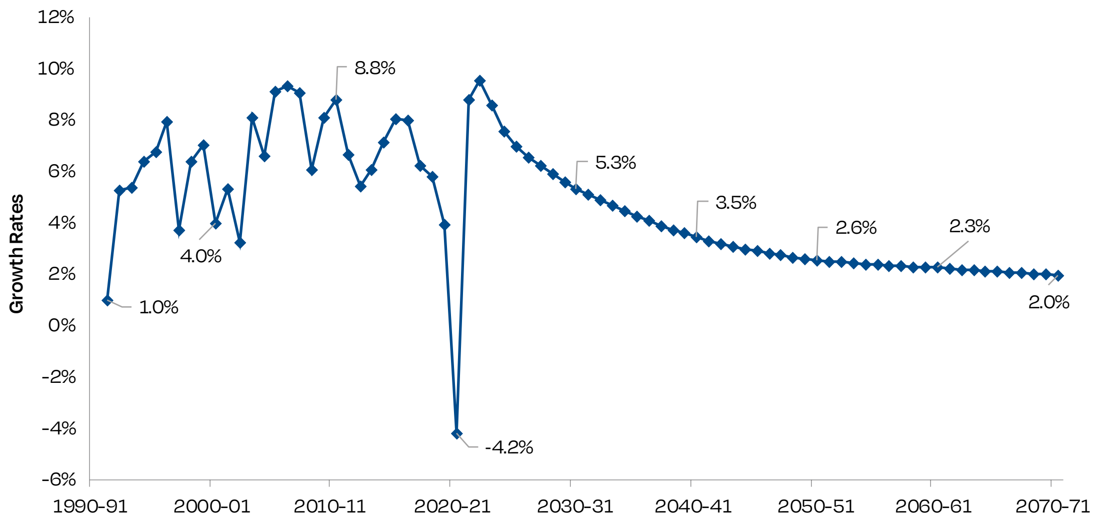
Where,

G_m = GHG emission from mode m, $V_{m,f}$= on-road vehicles of mode m and fuel type f, $U_{m,f}$= fleet utilization of vehicles of mode m and fuel type f, $D_{m,f}$= average dynamic-utilization of vehicles of mode m and fuel type f, $M_{m,f}$= average mileage (fuel efficiency) of vehicles of mode m and fuel type f, and EF_f= emission factor of fuel type f.

5.2 Macro-variables

The main exogenous variables are GDP and population. GDP forecast (2021–22 onwards) is based on the growth rate of long-term real GDP projected by OECD (2021) for India, and the actual GVA at constant 2021–22 prices. Figure 5.3 shows the growth trend of real GDP derived from OECD projections.

Figure 5.3: Real GDP growth trend



Notes: Growth rates till 2021–22 are based on real GDP growth rates derived from MoSPI. Growth rates during 2060–61 and 2070–71 are forecasted based on the decadal growth trend for 2050–51 and 2060–61. Real GDP growth projections from IMF World Economic Outlook (2023) and OECD Economic Outlook (2021) are very similar; however, IMF projections are available till 2029, which projects the growth rate to be 6.3 percent, whereas OECD projects it to be 6 percent.

Source: TERI's estimate based on real GDP from MoSPI, projection by OECD (OECD, 2021)

Table 5.2 lists the historical GDP (real, at constant 2011–12 prices) and population (pertaining to 1990–91 till 2020–21) and the projected decadal values (till 2070–71). GDP per capita is derived from GDP and population.

Table 5.2: GDP and population– Historical trends and projections

Years	Population (billion)	Real GDP (INR billion)	Real GDP per capita (INR)
1990–91	0.87	22,112	25,403
2000–01	1.06	37,353	35,251
2010–11	1.24	75,996	61,257
2020–21	1.40	126,815	90,816
2030–31	1.51	251,980	166,324
2040–41	1.61	380,681	236,202
2050–51	1.67	506,348	303,114
2070–71	1.69	788,400	466,445

Note: GDP is measured at 2011–12 constant prices. GDP estimates for 2022–23 onwards are based on the growth rate of real GDP long-term projections by OECD (2021) for India.

Source: UN-DESA (2023), GoI (2023), RBI (2017), OECD (2021)

Further, TERI-TptM adopts a saturation curve-fitting approach (sigmoid curves) to estimate transport demand for both road and railways. Under such an estimation approach, transport activity first accelerates and after reaching a point of inflexion the growth in transport activity slows down and tends to saturate. This is associated with the economic progress of a country, greater income, and reduced transportation need due to plateauing impact of population dynamics and limitations imposed by geographical boundaries. Table 5.3 lists the saturation points considered for different modes of transport by TERI-TptM. For road transport vehicles, the average lives of vehicles for each of the modes are also assumed for estimating on-road vehicles from the cumulative stock of registered vehicles (available from MoRTH) and presented in Table 5.3. The saturation levels for each segment indicate the maximum achievable value in future. Average life of vehicle indicates the maximum years an average vehicle in any category can run on the roads (technologically or based on policy interventions). The choices of saturation levels for road vehicle densities rely primarily on literature.

Table 5.3: Assumed saturation levels and average life of vehicles

Operation	Modes	Saturation Levels		Average Life of Vehicle (years)
		No. of Vehicles per 1,000 Population	Km per capita or BTKM	
Passenger	Two-wheeler (2W)	300	-	10
	Three-wheeler (3W-P)	50	-	12
	Four-wheeler- Cars & Jeeps (4W-C&J)	200	-	15
	Four-wheeler- Taxis (4W-T)	20	-	12
	BUS	3	-	15
	Railways (km/capita)	-	2,500	-
Freight	LGVs	25	-	15
	MHGVs	25	-	15
	Railways (BTKM/year)	-	7,500	-

Source: TERI's assumption based on stakeholder consultations, Hossain et al. (2023), Singh et al. (2020), Arora et al. (2011), and Singh (2006)

Further, India's per capita GDP in 2070–71 at 2021–22 prices and exchange rate is estimated at 9,784 USD.[52] At 2021 current prices seven major economies had similar per capita GDP (varying between 7,000 and 13,000 USD), these are- Argentina, Brazil, China, Kazakhstan, Malaysia, Mexico, and Türkiye. Average motor vehicle (cars, three-wheelers, vans, bus, and goods vehicles) density per thousand population in this group of countries is 357. The assumed aggregate motor vehicle (excluding two-wheelers) saturation for India translates to 323 (see Table 5.3).

In this report, unless otherwise specified, 2W denotes two-wheelers; 3W- P denotes three-wheeler passenger vehicles; 4W- C&J denotes four-wheeler cars and jeeps; 4W- T denotes four-wheeler taxis/cabs; BUS consists regular-sized bus and omni-bus; LGV denotes the light goods vehicles and consists of 3W and 4W goods vehicles (GVW ≤ 7.5 tonnes); MHGV denotes the medium and heavy goods vehicles and consists of vehicles with GVW above 7.5 tonnes.

[52] Estimated per capita GDP (at 2011–12 constant prices) in 2070–71 is INR 4,66,445 which translates to INR 7,24,746 at 2021–22 current prices. When converted to USD (average exchange rate of 1 INR = 0.0135 USD, in 2021) it translates to USD 9,784.

5.3 Methodology

There is significant correlation between historical GDP per capita and passenger vehicles per thousand population (correlation coefficients are- 0.9943, 0.9667, 0.9969, 0.9841, and 0.8800 respectively, for 2W, 3W- P, 4W- C&J, 4W- T, and BUS). Similarly, high correlation exists between per capita GDP and BPKM for railways and aviation (0.9352, 0.9758 respectively). For the road freight segment too, there is high correlation between GDP and number of LGVs and MHGVs per thousand population (0.9860, 0.9417 respectively). Correlation coefficients between GDP and BTKMs for railways and aviation too indicate high level of association (0.9872, 0.9816 respectively).

Literature on projection of vehicle stock and transport activities is quite rich (Fulton and Eads, 2004; Singh, 2006; Bouachera and Mazraati, 2007; Schipper et al., 2008; Arora et al., 2011; Singh et al., 2020), however, the approaches and vehicle types differ considerably. The relationship between GDP per capita (or GDP) and passenger vehicle density (or freight activity) does not follow a typical linear relationship, and the most common method used to project vehicle stock/ transportation activities is fitting the sigmoid family of curves, particularly Logistic and Gompertz (Dargay et al., 2007), to account for an accelerated transport demand followed by a slowdown and saturation in transport activities.

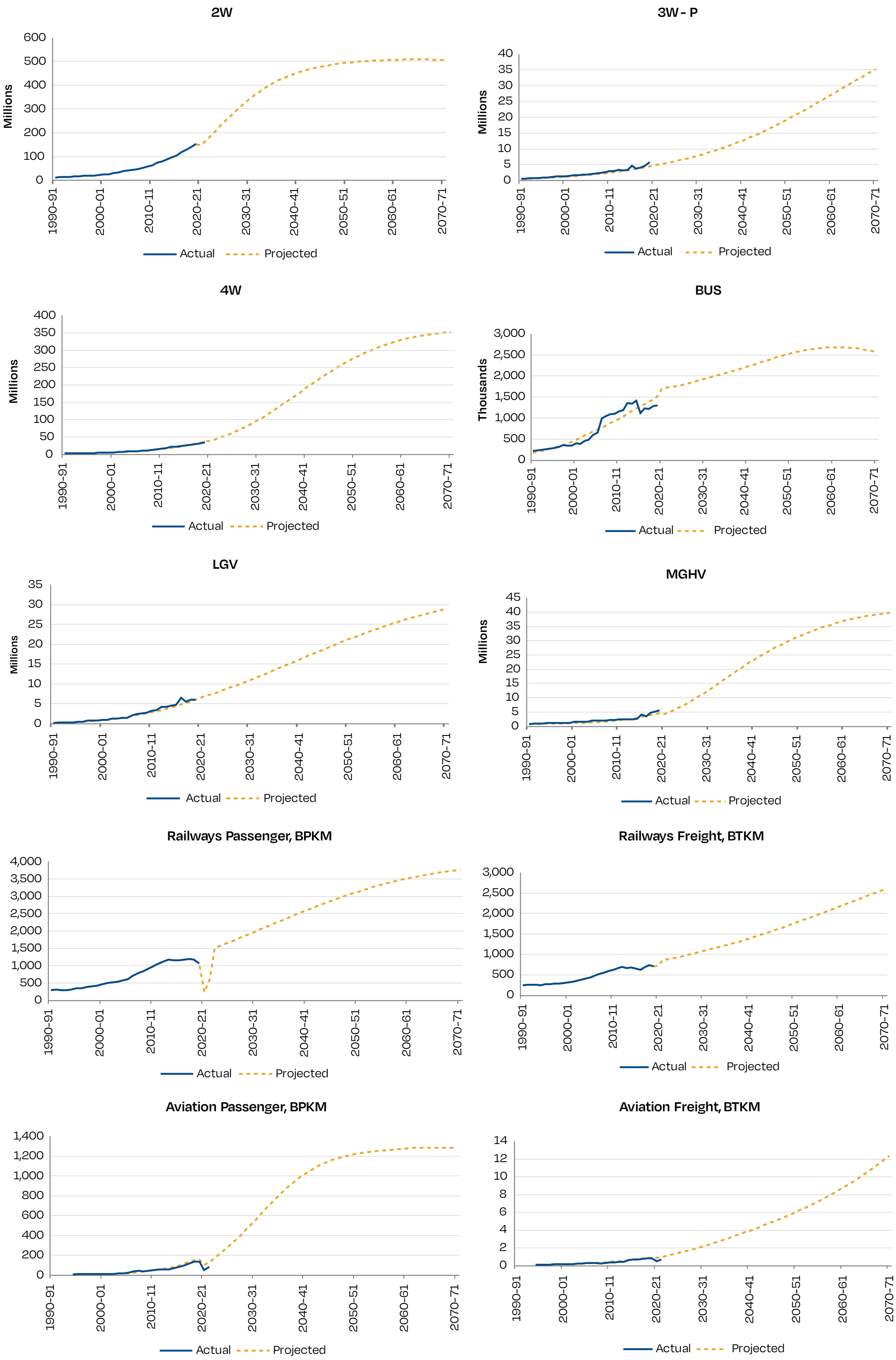
Alternative sigmoid family of curves were fitted for land-based modes of transport. However, for aviation no *a priori* assumption was adopted on saturations and the passenger and freight transport demands (PKM and TKM) were estimated based on growth rates of GDP per capita and GDP respectively (both at 2011–12 constant prices) using ordinary least square estimates (OLS).[53] The next section presents the transport demand projections for different modes of transport based on the fitted models.

5.4 Transport Demand Forecasting

Figure 5.5 presents the projected values of number of vehicles vs the actual numbers of vehicles in each of the road vehicle segments and the projected vs actual transport demands for railways and aviation.

[53] Growth rates were modelled instead of levels to address the problem of non-stationarity in transport demand and GDP.

Figure 5.4: Model fit– Actuals vs forecasts



Note: Model fit for aviation- freight is insignificant in all alternative model specifications, possibly due to lesser number of data points and weak relation with GDP, at least in Indian context.

Source: TERI-TptM

From Figure 5.4 it is evident that the models predict the actual values accurately in all the cases except for Bus segment, for which the erratic behaviour of the actual values are responsible for relatively weaker fit of the model. The number of road transport vehicles that are in use at different time points are presented in Table 5.4.

Table 5.4: Estimated number of in-use road transport vehicles in India

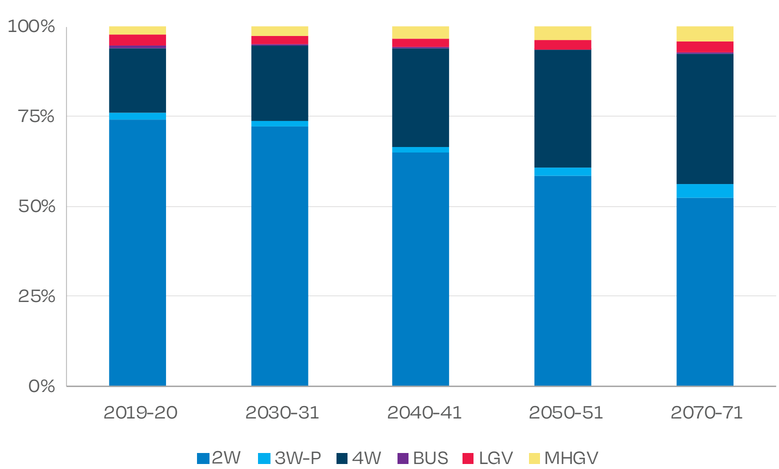
Years	Number of Vehicles (in million)						
	2W	3W-P	4W	BUS	LGV	MHGV	Total
2019–20	151	4	36	2	6	5	204
2030–31	342	8	98	2	11	13	474
2040–41	454	13	191	2	16	23	700
2050–51	495	19	278	3	21	32	847
2070–71	507	35	352	3	29	40	966

Note: 4W includes 4W- C&J and 4W- T.

Source: TERI-TptM

The number of 2Ws is expected to increase more than 3.5 times between 2019–20 and 2070–71 with visible saturation starting 2050–51. Autorickshaws (3W- P) are poised to experience an eight-fold increase during the same period and unlikely to show any saturation despite a decline in growth rate. Number of four-wheelers (4W- C&J and 4W- T combined) is expected to multiply almost 10 times with possible saturation occurring in late 2060's. Number of buses is expected to increase the least (less than double) among all the modes and likely to reach saturation by 2055–56. Number of LGVs will increase almost by five-fold whereas MHGV segment is expected to grow more than eight-fold during 2019–20 and 2070–71, and likely to saturate. The relative distribution (Figure 5.5) highlights a declining share of 2W and a mostly being captured by the 4W segment.

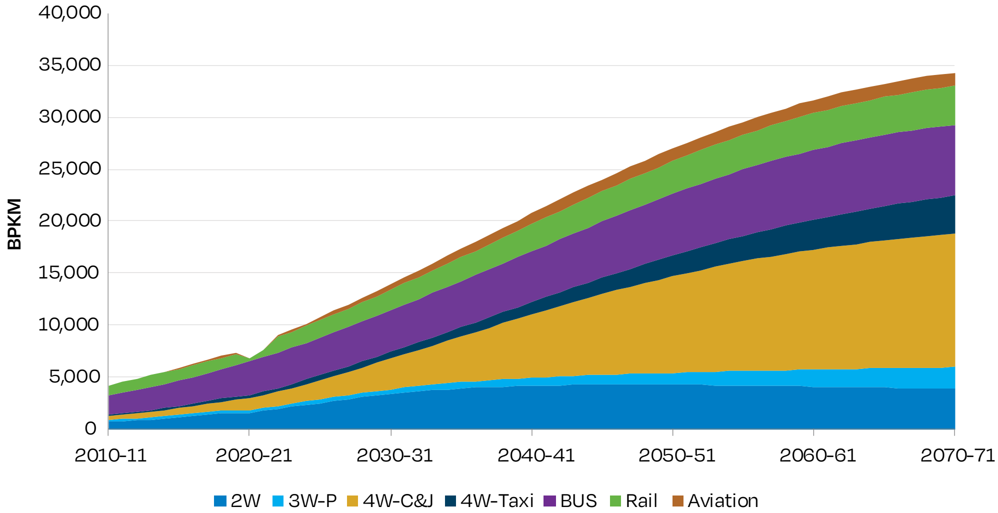
Figure 5.5: Estimated distribution of on-road vehicles



Source: TERI

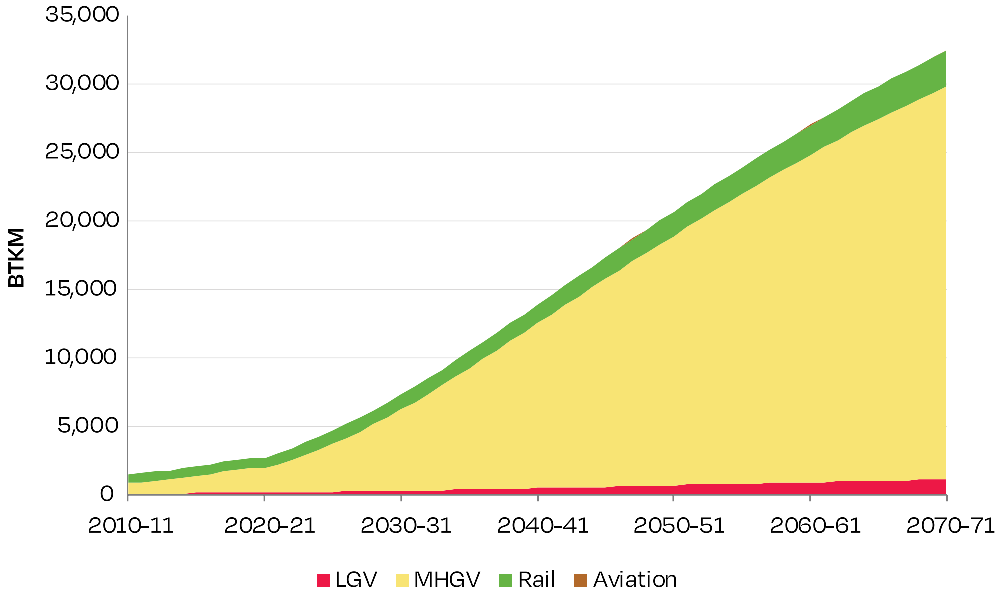
Based on the estimation of number of vehicles on road and the transport demand in railways and aviation, Figure 5.6 and Figure 5.7 present the passenger and freight transport demand, measured in BPKM and BTKM respectively.

Figure 5.6: Passenger transport demand– Sectoral decomposition



Source: TERI

Figure 5.7: Freight transport demand– Sectoral decomposition

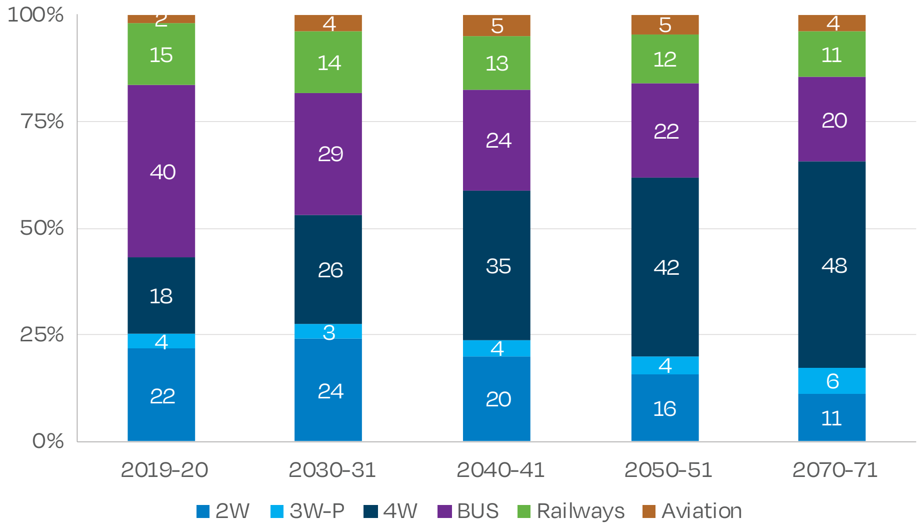


Source: TERI

Passenger demand is expected to increase from 7,303 BPKM in 2019–20 to 13,941 in 2030–31, 20,724 in 2040–41, and 26,983 in 2050–51. By 2070–71 it is projected to increase by more than 4.3 times from 2019–20 value and is expected to reach 34,284 BPKM. This translates to an increase in per capita passenger transport demand from 5,280 PKM in 2019–20 to 9,202 PKM in 2030–31, 12,859 PKM by 2040–41, 16,152 PKM by 2050–51, and 20,283 PKM by 2070-71. Freight transport demand is expected to increase from 2,682 BTKM in 2019–20 to 7,260 in 2030–31, 13,860 in 2040–41, and 20,644 in 2050–51. By 2070–71 it is expected to reach 32,370 BTKM, a significant increase from base year value. Consequently, per capita freight transport demand is expected to increase from 1,939 TKM in 2019–20 to 4,792 TKM in 2030–31, 8,600 TKM by 2040–41, 12,358 by 2050–51, and 19,152 by 2070–71.

It is projected that an inter-modal shift in passenger transport will be observed in India, as depicted in Figure 5.8. A shift from modes with less GHG footprint per PKM (2W and Bus) to four-wheelers will be observed, and by 2070–71 it is expected that the modal share of 4W will be more than the combined modal shares of BUS and 2W (31 percent).

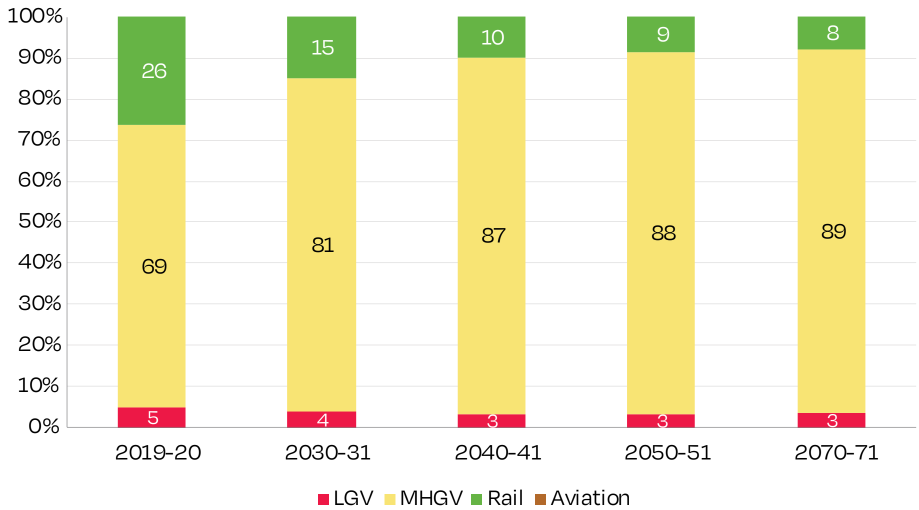
Figure 5.8: Projected modal-split in passenger transport



Source: TERI

Figure 5.9 depicts the long-term trends in modal shares in freight transport. Domestic aviation contributes the least (0.03 percent in 2019–20) and is expected to remain stagnant at 0.04 percent by 2070–71.

Figure 5.9: Projected modal-split in freight transport



Note: TERI-TptM demand estimates are based on past trends, the declining share of railways is possibly linked to the gradual decline of railways in freight transportation (see TERI, 2023; GoI, 2022).

Source: TERI

In freight transport, the shift towards road will continue and MHGVs will contribute almost 90 percent of freight movement by 2070–71. The share of railways will continue to decline from an estimated 26 percent in 2019–20 to 8 percent by 2070–71, despite an expansion of railways' freight operation.

5.5 Assumptions

5.5.1 Fuel-split in Road Transport

The projections of road transport demand in TERI-TptM assume fuel-split trajectories over the projection timeframe. Figure 5.10 depicts the assumed fuel-split trajectories (of vehicle stock) in which 2020–21 values are matched with corresponding fuel-split information available from the Vahan database.

Figure 5.10: Fuel-split trajectory- Baseline assumption

Source: TERI

Electric vehicles (EV) contributed estimated 0.6, 0.7, 0.2, 0.5, 0.2, 0.6, and 0.05 percentages in 2W, 3W- P, 4W- C&J, 4W- T, Bus, LGV, and MHGV segments respectively by September 2023.[54] It is assumed under the baseline scenario that the increasing electrification will continue, showing significant impact in 2W, 3W- P, 4W- C&J, 4W- T, and LGV in-use vehicle stock and contributing 18, 27, 18, 28, and 18 percentages respectively by 2070–71. EV penetration in BUS and MHGV segments under the baseline scenario is assumed to reach 5.4 and 3.4 percentages respectively by 2070–71. Table 5.5 lists the assumed penetration of electric vehicles in different road vehicle segments.

Table 5.5: EV penetration– Assumptions

Years	Assumed Percentage (%) of EVs in in-use Vehicle Stock					
	2W	3W-P	4W	Bus	LGV	MHGV
2019-20	0.5	0.5	0.2	0.3	0.5	0.0
2030-31	2.5	5.6	1.0	0.8	2.5	0.3
2050-51	9.3	21.0	6.6	2.2	10.1	1.5
2070-71	26.7	33.0	18.9	5.4	18.5	3.4

Note: 4W includes 4W-C&J and 4W-T.

Source: TERI

Based on the assumptions on fuel-split in road transport and the transport demand projections, the TERI-TptM estimates the fuel demand and energy usage in the transport sector, discussed in next section.

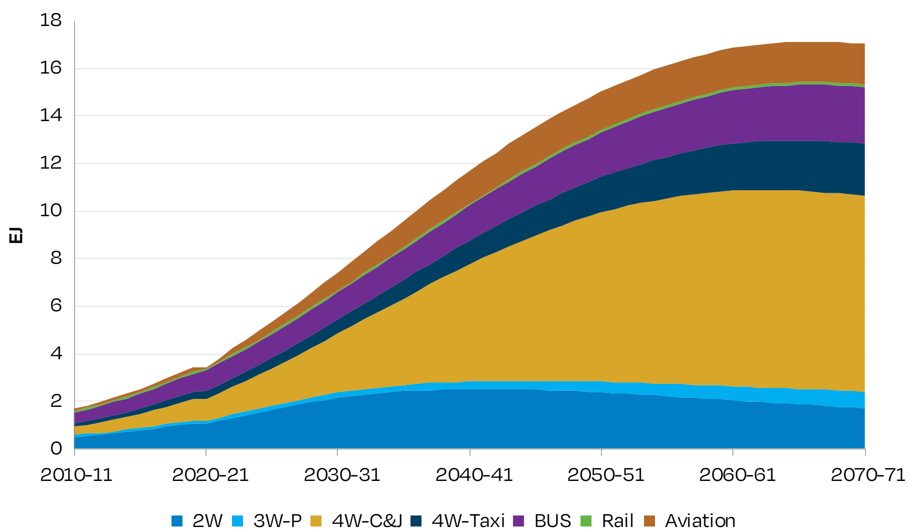
5.6 Energy and Fuel Demand

Energy and fuel demand are estimated separately for passenger and freight segments. In the baseline scenario, no blending of biofuel is considered for diesel, ATF, and natural gas, however, ethanol blending of 10 percent is considered for petrol.

5.6.1 Passenger Transport

Figure 5.11 and Figure 5.12 present the energy demand (measured in exa-Joules, EJ) and fuel usage (measured in million-tonnes of oil equivalent, Mtoe) from passenger transport.

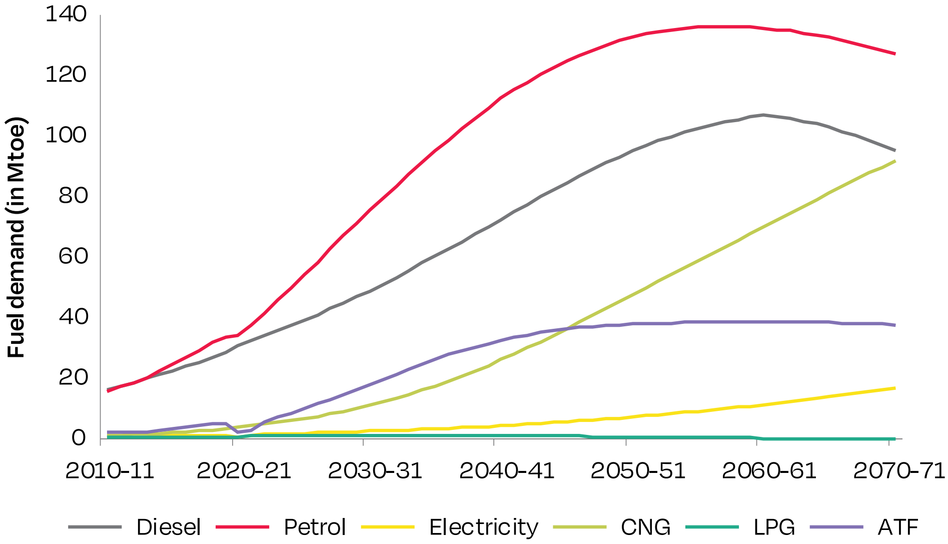
Figure 5.11: Energy demand– Passenger transport



Source: TERI

[54] Vahan dashboard accessed from https://vahan.parivahan.gov.in/vahan4dashboard/ (as on September 16, 2023).

Figure 5.12: Fuel demand– Passenger transport



Source: TERI

Energy demand from diesel and petrol will increase; however, the increase will be faster for petrol, owing to greater penetration of 2Ws and petrol 4Ws in India. Diesel demand will peak at 107 Mtoe by 2060–61, whereas petrol demand is expected to peak at 136 Mtoe by 2056–57. Demand for aviation turbine fuel (ATF) will stagnate around 38 Mtoe by 2050, and CNG and electricity demand will increase considerably. The percentage distribution of fuel demand at different time-points is presented in Table 5.6.

Table 5.6: Percentage distribution of fuel demand– Passenger transport

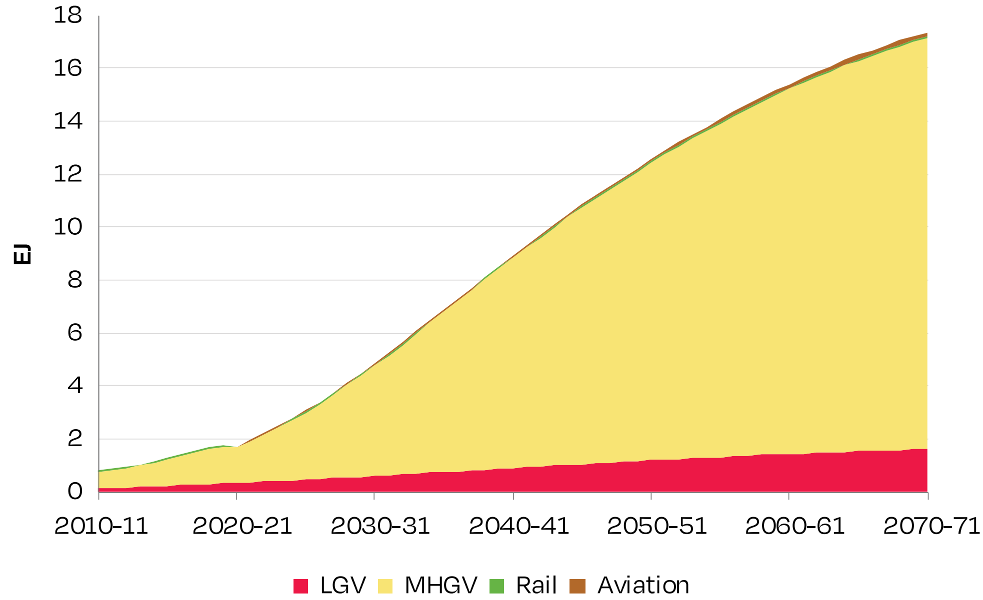
Years	Fuel Demand											
	Diesel		Petrol		Electricity		CNG		LPG		ATF	
	%	Mtoe	%	Mtoe	%	**Mtoe**	%	**Mtoe**	%	**Mtoe**	%	**Mtoe**
2019–20	40.1	29	47.1	34	1.2	0.83	4.5	3.20	0.7	0.52	6.4	4.56
2030–31	31.2	49	48.4	75	1.5	2.36	7.0	10.88	0.5	0.80	11.4	17.82
2050–51	29.6	95	41.5	133	2.2	6.98	14.8	47.46	0.1	0.41	11.8	37.67
2070–71	25.8	95	34.4	127	4.5	16.61	24.9	91.72	0.0	0.00	10.2	37.55

Source: TERI

5.6.2 Freight Transport

Figure 5.13 and Figure 5.14 present the energy demand (measured in EJ) and fuel usage (measured in Mtoe) from freight transport. Energy demand from railways is negligible and predicted to remain negligible owing to electrification of traction and a consistent modal-shift from railways to road.

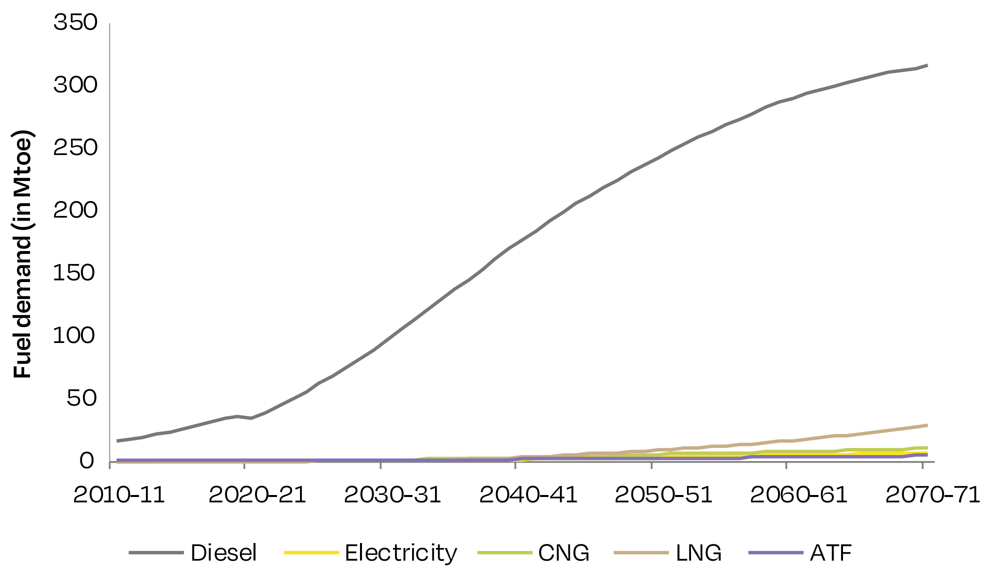
Figure 5.13: Energy demand– Freight transport



Source: TERI

The dominance of the MHGV segment in energy demand is poised to increase from 79 percent in 2019–20 to 89 percent in 2070–71, owing to an expected increase in its share in freight transport from 69 to 89 percent during the same period.

Figure 5.14: Fuel demand– Freight transport



Source: TERI

The increasing demand for diesel will continue (however, at a decreasing rate) due to negligible penetration of electric vehicles in MHGV segment. The percentage distribution of fuel types in energy demand mix in freight transportation at different time-points are presented in Table 5.7.

Table 5.7: Percentage distribution of fuel demand– Freight transport

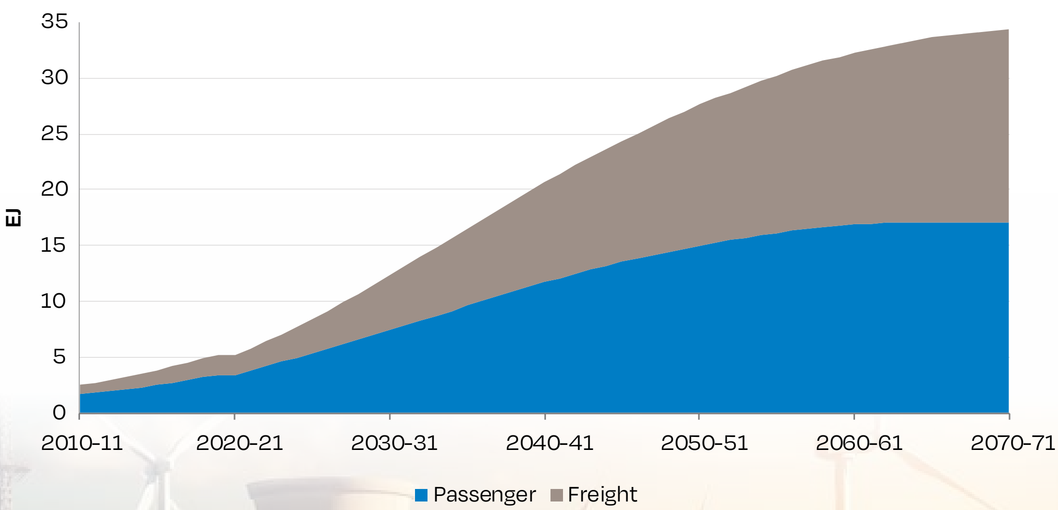
Years	Fuel Demand									
	Diesel		Electricity		CNG		LNG		ATF	
	%	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe
2019–20	97.1	36	1.1	0.40	0.9	0.34	0.0	0.00	0.9	0.33
2030–31	96.6	97	0.8	0.84	1.2	1.17	0.5	0.53	0.9	0.88
2050–51	92.4	242	1.1	2.87	2.1	5.57	3.5	9.21	0.9	2.31
2070–71	86.3	316	1.9	7.08	2.8	10.14	7.7	28.30	1.2	4.47

Source: TERI

5.6.3 Energy Demand

Energy demand from transport is expected to increase from 5.21 EJ in 2019–20 to 12.27 EJ, 20.62 EJ, 27.59 EJ, and 34.39 EJ in 2030–31, 2040–41, 2050–51, and 2070–71 respectively. The dominance of passenger transport is expected to decline from 66 percent of total energy demand in 2019–20 (3.43 EJ) to 49 percent (17.02 EJ) in 2070–71, owing to the faster growth in freight activities and greater electrification of passenger transport. Relative distribution of passenger and freight in energy demand is shown in Figure 5.15.

Figure 5.15: Transport sector energy demand– Passenger vs freight



Source: TERI

5.6.4 Model Validation

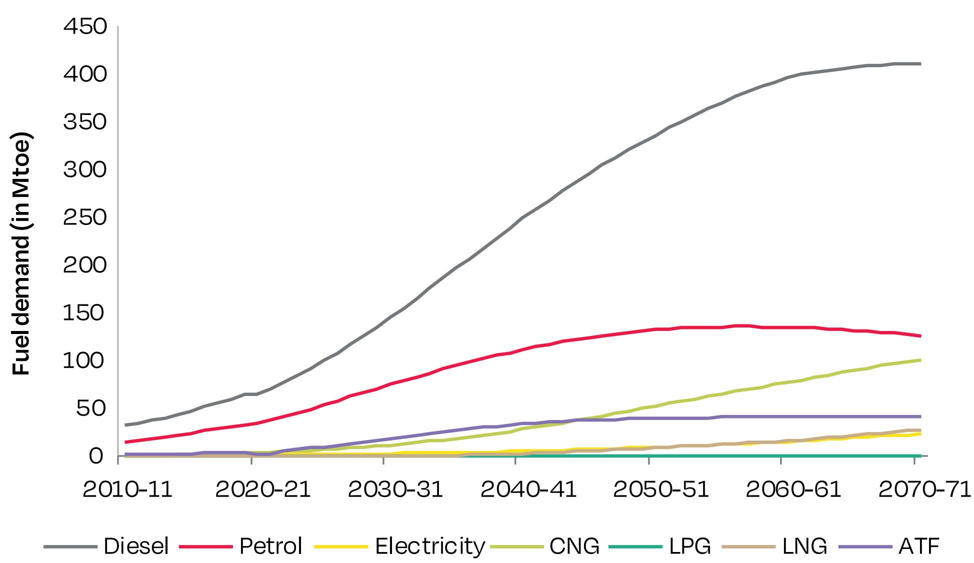
As a validation exercise the estimated fuel demand from the model was compared with the reported domestic consumption of corresponding fuel type reported by the Petroleum Planning & Analysis Cell (PPAC) of the Ministry of Petroleum and Natural Gas (MoPNG), GoI. As per the model, the consumptions of petrol (net of ethanol), diesel, and ATF were estimated at 47.07, 89.06, and 7.07 billion litres respectively in 2022–23, as against the reported consumptions of 46.45, 101.88, and 9.21 billion litres respectively (PPAC). However, transport activities within India accounts for almost entirety of petrol, 80 percent of diesel, and 75 percent of ATF consumption (PPAC). Under such assumptions, TERI-TptM overpredicts consumption of petrol, diesel, and ATF by 1.3, 8, and 2 respectively (no blending for diesel and ATF, 10 percent ethanol blending with petrol).

The projected per capita passenger and freight transport demands (see Section 5.4) are similar to the findings by Tjandra et al. (2024), observed for emerging economies (including India). They project the per capita passenger transport demand (excluding waterways) to grow from around 6,000 PKM in 2020 to around 19,000 PKM in 2050. And they project the freight transport demand to grow from around 3,000 TKM to almost 12,000 TKM by 2050. TERI-TptM estimates the per capita passenger transport demands for India to be 4,900 PKM in 2020-21 and 16,152 PKM in 2050-51. Whereas the corresponding per capita demand for freight transport is estimated at 1,869 TKM in 2020-21 and 12,358 in 2050-51.

5.6.5 Fuel Demand

Energy demand from fossil fuels will continue to increase; however, the growth will be at a declining rate, particularly for petrol and diesel, as depicted in Figure 5.16. Under the baseline scenario, petrol demand is expected to reach 75 Mtoe by 2030–31, 133 Mtoe by 2050–51, and 127 Mtoe by 2070–71. Diesel demand is expected to reach 146 Mtoe by 2030–31, 227 Mtoe by 2050–51, and 411 Mtoe by 2070–71. The natural gas demand (CNG and LNG) is expected to reach 13 Mtoe by 2030–31, 62 Mtoe by 2050–51, and 130 Mtoe by 2070–71.

Figure 5.16: Fuel demand from transport in India



Source: TERI

Under the baseline scenario, demand for petrol will peak by 2057–58 (155 billion litres, 172 billion litres including 10 percent blended ethanol) and falling thereafter, and diesel demand will reach its peak by 2068–69 (467 billion litres). CNG demand and electricity demand will increase, though big push is required for these to have significant impact on aggregate fuel demand. ATF demand will remain stable during 2060–61 and 2070–71 after attaining its peak of 49 billion litres. Table 5.8 lists the projected demand for fuels in transport sector at different time-points.

Table 5.8: Projected fuel demand– Transport sector

Years	Fuel Demand (in Mtoe)							
	Diesel	Petrol	Electricity	CNG	LPG	LNG	ATF	TOTAL
2019–20	64.5	33.6	1.2	3.5	0.5	0.0	4.9	108.3
2030–31	145.7	75.4	3.2	12.1	0.8	0.5	18.7	256.4
2050–51	336.8	132.7	9.8	53.0	0.4	9.2	40.0	582.0
2070–71	410.8	127.0	23.7	101.9	0.0	28.3	42.0	733.7

Source: TERI

Dominance of diesel will continue but expected to reduce marginally from 60 percent in 2019–20 to 56 percent in 2070–71. Diesel demand is expected to grow from 73 billion litres in 2019–20 to 166 billion in 2030–31, 283 billion in 2040–41, 383 billion in 2050–51, and 467 billion litres in 2070–71. Diesel demand growth however will start moderating from early 2060–61. Consequently, petrol demand (without 10 percent ethanol blend) is expected to expand from 38 billion litres in 2019–20, to 86 billion in 2030–31, 128 billion in 2040–41, and 151 billion in 2050–51. However, petrol demand is expected to fall considerably starting early 2060s and is expected to reach 144 billion litres by 2070–71. ATF demand is expected to increase from 6 billion litres in 2019–20 to 22 billion litres in 2030–31, 40 billion litres in 2040–41, and 47 billion litres in 2050–51. It will stabilize at 49 billion litres by 2058–59 and thereafter. Table 5.9 presents the demands (in volume) for three major petroleum fuels (petrol, diesel, and ATF) under the baseline scenario.

Table 5.9: Projected petroleum product demand– Transport sector

Years	Fuel Demand in billion litres		
	Diesel	Petrol	ATF
2019–20	73	38	6
2030–31	166	86	22
2050–51	383	151	47
2070–71	467	144	49

Note: Petrol demand in the table is measured without 10 percent ethanol blending.

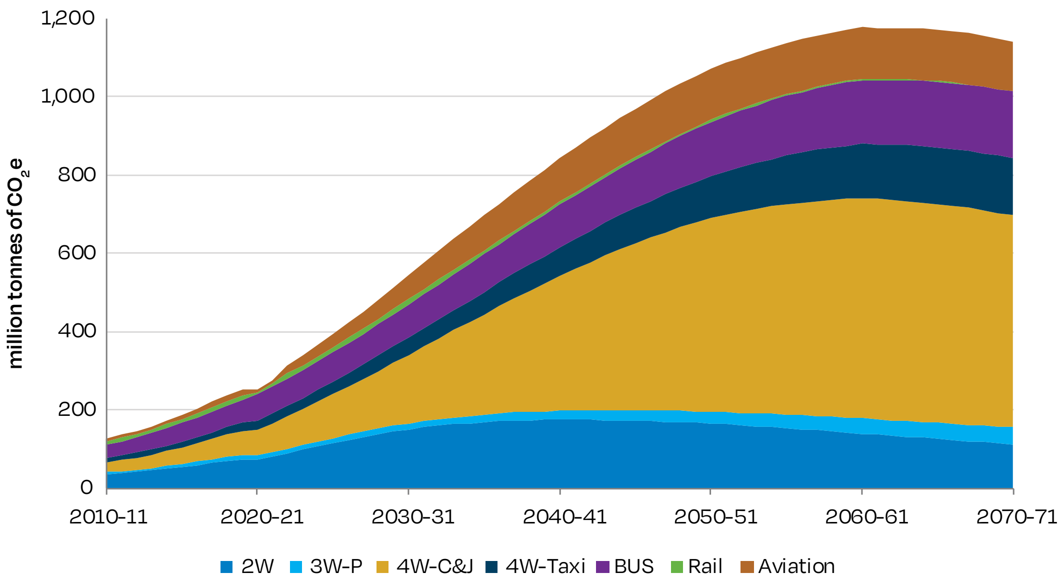
Source: TERI-TptM

The next section discusses the GHG impact of India's transport sector, based on the TERI-TptM projections.

5.7 GHG Emissions

In this report GHG emissions are measured (in million tonnes of CO_2 equivalent, CO_2e) and limited to-carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).[55] GHG emissions in this report correspond to well-to-wheel (WTW) emission, unless otherwise specified. Figure 5.17 depicts the GHG emissions from different modes of passenger transport. Emissions are expected to increase 4.5 times, from 253 to 1,142 million tonnes of CO_2e between 2019–20 and 2070–71, achieving its peak at 1,177 million tonnes of CO_2e by 2060–61.

Figure 5.17: GHG emissions from passenger transport

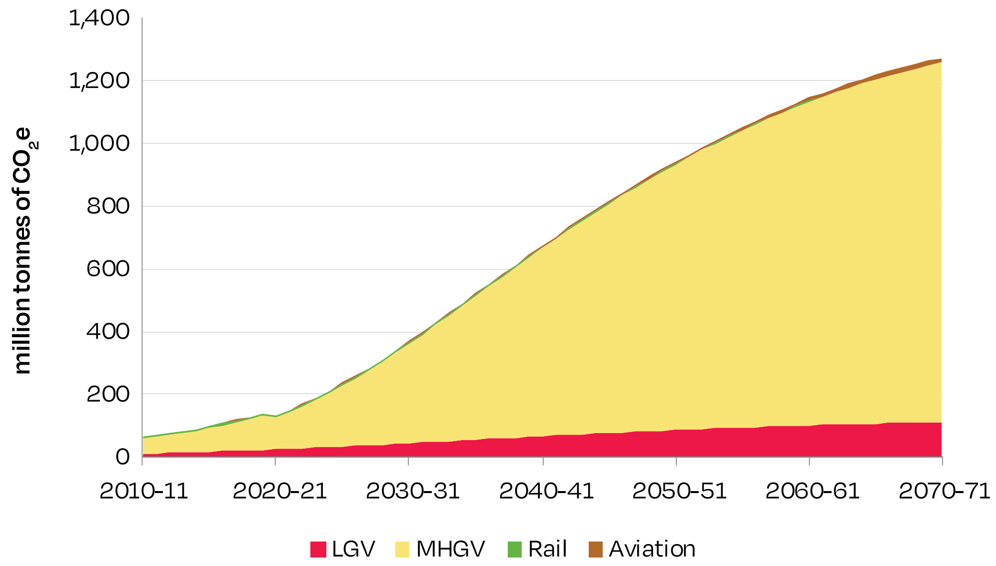


Source: TERI

Emissions from freight transportation will be dominated by MHGV segment as depicted by Figure 5.18. GHG emission is expected to increase almost ten-times, from 138 to 1,274 million tonnes of CO_2e during 2019–20 and 2070–71, of which MHGV segment is poised to increase its dominance from 78 to 90 percent, owing to relatively lower penetration of electric vehicles in the segment.

[55] Emission from electricity is based on TERI Estimate (Rodrigues et al., 2023) and only reflects CO2 emissions. Emission factors and energy contents for diesel, petrol, natural gas, LPG, ethanol blended petrol, and biodiesel blended diesel are from DIN EN 16258: 2013-03. The emission factors and energy contents corresponding to jet kerosene (jet A1 and jet A) and sustainable aviation fuel (SAF) (HVO/HEFA, 50 percent rapeseed and 50 percent used cooking oil) are from ISO 14083:2023. Emission factor for green-hydrogen is from Green Hydrogen Organization, and energy content of green-hydrogen is from https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx

Figure 5.18: GHG emissions from freight transport



Source: TERI

In line with the distribution of energy demand, the dominance of passenger transport in its contribution to GHG emission will wane by 2070–71. During 2019–20, passenger transport accounted for 65 percent of total emissions from transport (253 million tonnes of CO_2e), however, its share is projected to decline to 47 percent by 2070–71 (1,142 million tonnes of CO_2e), owing to greater electrification in passenger segment compared to freight, and saturation in passenger transport demand. GHG emissions from different modes of transport are listed in Table 5.10.

Table 5.10: Projections of GHG emissions from transportation in India

Years	GHG Emission from Modes of Transport, in million tonnes of CO_2e									
	Road							Railways	Aviation	TOTAL
	2W	3W-P	4W	BUS	LGV	MHGV	ALL			
2019–20	74	9	85	59	24	107	358	16	17	391
2030–31	150	16	219	84	45	316	830	19	64	914
2050–51	165	31	601	138	86	847	1,868	9	137	2,015
2070–71	112	43	689	170	111	1,147	2,272	0	144	2,416

Source: TERI

GHG emission from transport under the baseline scenario is poised to increase more than six time during 2019–20 (the base year) and 2070–71. Emissions will more than double in near-term, increase by 1.7 times in medium-term, 1.3 times in distant, and 1.2 times in vague phases. Road transport will continue to dominate the emission from transport with over 90 percent share throughout the timeframe of analysis.

6

Transport Decarbonisation Scenarios and Results

Chapter 5 discussed in detail the baseline trajectory of Indian transport sector (road, railways, and aviation). Passenger transport demand is expected to more than quadruple between the base year (2019–20) and 2070–71, whereas freight transport demand is poised to grow over 13 times during the same timeframe. Corresponding GHG emissions will however increase by 5 times and more than 9 times respectively.

Mitigation strategies to address the growing GHG emission from transport in India involves multitudes of policies that encompass biofuel blending, identifying sectors for introducing natural gas, and alternative technologies (involving battery electric vehicles and hydrogen as fuel) as viable options. Further, improved technological efficiencies and revised fuel economy standards have clear impact on reduction of emission from internal combustion engine (ICE) vehicles and reduced energy requirements for alternative fuel vehicles. India is a party to the **EV30@30** campaign that envisions a 30 percent electric vehicle (EV) share in the newly registered vehicles by 2030 and is moving fast with electrification of some of the modes of road transport, particularly three-wheelers. It is expected that India will witness greater adoption of EVs in future, though the adoption for medium-heavy goods vehicles (MHGVs) will be relatively slower, as this emerges as the hard-to-abate sector in road transport. However, the advancements of hydrogen as fuel and liquified natural gas (LNG) are poised to have accelerated impact on MHGVs and buses (long-distance intercity transport) as these may address range anxiety (and longer charging time requirements) and the battery weight penalty issue associated with electrification of MHGVs. LNG has considerable potential in fixed circuitous routes like mining belts, routes linking ports to the manufacturing hubs, etc.

India is expected to expand its biofuel blending with petrol, diesel, compressed natural gas (CNG), and aviation turbine fuel (ATF). The updated National Policy on Biofuels has set a target of ethanol blending of 20 percent with petrol by 2025, and 5 percent blending of biodiesel with diesel by 2030. Additionally, the 'CBG Blending Obligation' of the government targets a 5 percent blending of compressed biogas (CBG) with CNG by 2028–29, and an indicative target set by the government on use of sustainable aviation fuel (SAF) envisions a 2 percent SAF blending by 2028 (initially for international flights).

To assess the impact of different technology and policy-driven mitigation approaches to decarbonise transport sector in India, three scenarios were identified in this study-

- **Policy-in-action (PIA) -** the policy targets are met (by 2030–31) with increased adoption of EVs, hydrogen, LNG, and CNG beyond 2030–31. The blending possibilities remain unchanged beyond 2030–31.
- **Ambitious -** the policy targets are met (by 2030–31) and the country moves to a faster adoption path for different fuel technologies and blending potentials (compared to PIA trajectories).
- **Highly Ambitious –** the policy targets are met (by 2030–31) and there is a considerable shift to EVs and hydrogen as fuel, as compared to the Ambitious scenario. Blending potentials remain the same as in the Ambitious scenario.

There are few commonalities between the three scenarios-

- Fuel efficiency improvements for different vehicle segments over the baseline scenario are assumed to be same
- The penetration of renewable energy sources in the electricity grid (ex-bus generation) follows the same pattern under all the scenarios.

Table 6.1 provides an overview of the two scenarios and comparison with the baseline.

Table 6.1: Overview of scenarios

Scenarios	Fuel Economy Improvement	Fossil Fuels in Grid	EV Adoption	Hydrogen as Fuel (Bus and MHGV)	Blending Target
Baseline	Fixed rate	Fixed at present rate of 72%	Low	Nil	10% ethanol
PIA	Periodic improvement over the baseline	Gradual reduction of fossil fuel share to 0% by 2070-71	Meets 30% target by 2030, increased adoption thereafter	Low adoption	Meets biofuel blending targets by 2030-31 and continues thereafter
Ambitious	Same as in PIA	Same as in PIA	Meets 30% target by 2030, higher adoption thereafter than under PIA	Low adoption but higher than under PIA	Meets bio-fuel targets by 2030-31 and increased adoption wherever feasible
Highly Ambitious	Same as in PIA	Same as in PIA	Meets 30% target by 2030, significantly higher adoption thereafter than under PIA	Moderate adoption	Same as in Ambitious

Note: The government of India is increasingly pushing for 'green' hydrogen. In this report only green hydrogen is considered, though the possible adoption (due to the cost differentials) trajectory for India is likely to start with grey hydrogen, then move to blue hydrogen, before introduction of green hydrogen.

Further, under the Ambitious and Highly Ambitious scenarios, two independent pathways have been considered. Pathway 1 (under both the scenarios) has higher adoption of natural gas in transportation compared to Pathway 2 (under both the scenarios) which moderates the rate of natural gas adoption, considering the possibility of the existing price differential between petroleum products (diesel and petrol) and natural gas (for transportation) to wane in future, owing to growing import dependence for natural gas and increasing diversion of natural gas to the industrial sector (mostly ammonia production for fertilizers, and in oil refineries).[56] Also, large-scale LNG uptake in transportation may be constrained by the cost of infrastructure, and investments in such infrastructure may end up creating stranded assets.[57]

6.1 Assumptions

The detailed assumptions under the scenarios are provided in Table 6.2. The three alternative scenarios (PIA, Ambitious, and Highly Ambitious) differ in terms of electrification of vehicle stock, shares of hydrogen and natural gas (CNG and LNG) in vehicles. There are also differences in biofuel blending in the three scenarios.

[56] See https://www.eia.gov/todayinenergy/detail.php?id=61423 (accessed on May 24, 2024).

[57] See https://www.orfonline.org/expert-speak/india-as-a-gas-based-economy-six-years-to-go (accessed on May 24, 2024).

Table 6.2: Detailed assumptions– Baseline, policy-in-action, ambitious, highly ambitious scenarios

Strategies	Targets		2020-21	Baseline			Policy-in-action			Ambitious			Highly Ambitious		
				2030-31	2050-51	2070-71	2030-31	2050-51	2070-71	2030-31	2050-51	2070-71	2030-31	2050-51	2070-71
Fuel Technology (% of vehicle stock)	EV	2W	0.50	2.5	9.3	26.7	15.0	45.3	75.0	15.0	47.7	100.0	15.0	60.7	100.0
		3W-P	0.60	5.6	21.0	33.0	22.6	56.8	100.0	22.6	86.0	100.0	22.6	95.2	100.0
		4W-C&J	0.2	0.8	6.2	18.3	4.3	26.5	47.8	4.2	34.9	57.3	4.2	38.2	75.6
		4W-Taxi	0.36	3.7	14.9	28.1	9.4	45.9	62.0	9.4	51.5	70.5	9.4	66.5	100.0
		BUS	0.30	0.8	2.3	5.6	6.4	25.4	47.8	6.4	33.7	51.6	6.4	40.3	76.8
		LGV	0.58	2.5	10.1	18.5	3.5	17.7	29.2	3.5	25.5	44.8	3.5	34.0	75.5
		MHGV	0.05	0.3	1.5	3.4	1.8	11.6	22.2	1.8	17.1	33.3	1.8	20.4	51.4
	Hydrogen	BUS	0	0	0	0	0.06	1.2	10.5	0.1	3.2	15.1	0.1	4.3	20.1
		MHGV	0	0	0	0	0.08	2.0	14.8	0.5	4.9	20.1	0.5	9.9	32.0
Biofuel Blending Targets (%)	Ethanol		10	10	10	10	20	20	20	20	20	20	20	20	20
	Biodiesel		0	0	0	0	5	5	5	5	10	10	5	10	10
	CBG		0	0	0	0	5	5	5	5	10	15	5	10	15
	SAF		0	0	0	0	2	2	2	2	20	50	2	20	50
Decarbonising Grid	Percentage of Fossil fuel in Ex-bus Electricity Generation		72	72	72	72	58	24	0	58	24	0	58	24	0

Note: Percentage of fossil-fuel in ex-bus electricity generation for different years are based on TERI's estimates till 2050 (Rodrigues et al., 2023) and 0% by 2070-71 is based on the national commitment of achieving net-zero by 2070.

Source: TERI

6.2 Electrification of Road Transport

India has embarked on the policy path of electrification of road quite late compared to the USA, European Union, and China. Unlike the growing interest in electrification of road transport in these countries starting as early as 1990s, India has been a laggard. The national level policy National Electric Mobility Mission Plan 2020 (NEMMP) came into effect in 2012, under which the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) was rolled out in 2015 to promote adoption of electric vehicles in India, through a mix of supply-side and demand-side incentives. Table 6.3 provides the assumptions on EV penetration in newly registered vehicles at different time points under the three alternative scenarios. The values for 2023–24 are based on the actual registration data sourced from *Vahan* database.[58]

Table 6.3: Electrification of road– Trajectories

Scenarios	Years	Percentage of EVs in Newly Registered Vehicles								EVs as % of Vehicle Stock
		2W	3W-P	4W-C&J	4W-Taxi	BUS	LGV	MHGV	ALL	
Actuals	2023-24	4.92	12.37	1.77	2.94	4.85	0.53	0.06	4.32	1.10
PIA	2030-31	35	50	9	20	13	10	5	29	12
	2050-51	75	100	30	75	40	20	15	58	39
	2070-71	100	100	50	90	70	30	25	78	55
Ambitious	2030-31	35	50	9	20	13	10	5	29	12
	2050-51	80	100	45	85	60	40	25	67	43
	2070-71	100	100	70	100	80	60	45	87	59
Highly Ambitious	2030-31	35	50	9	20	13	10	5	29	12
	2050-51	100	100	55	100	70	60	40	83	48
	2070-71	100	100	90	100	90	90	65	95	62

Source: TERI, Vahan dashboard (for 2023-24)

The three scenarios assume same EV penetration till 2030–31, as guided by the EV30@30 target, reaching an estimated 29 percent of newly registered vehicles by 2030–31. However, the adoption under the Ambitious scenario is assumed to be faster compared to the same under the PIA scenario. Highly Ambitious scenario has significantly high penetration of EVs compared to the Ambitious scenario. Table 6.3 has been utilised to estimate the EV penetration percentage in stock of vehicles at different time points (Table 6.2).

Based on the assumptions defining the three alternative scenarios, TERI-TptM projects the energy and fuel demand along with the well-to-wheel (WTW) GHG emissions. These are discussed next.

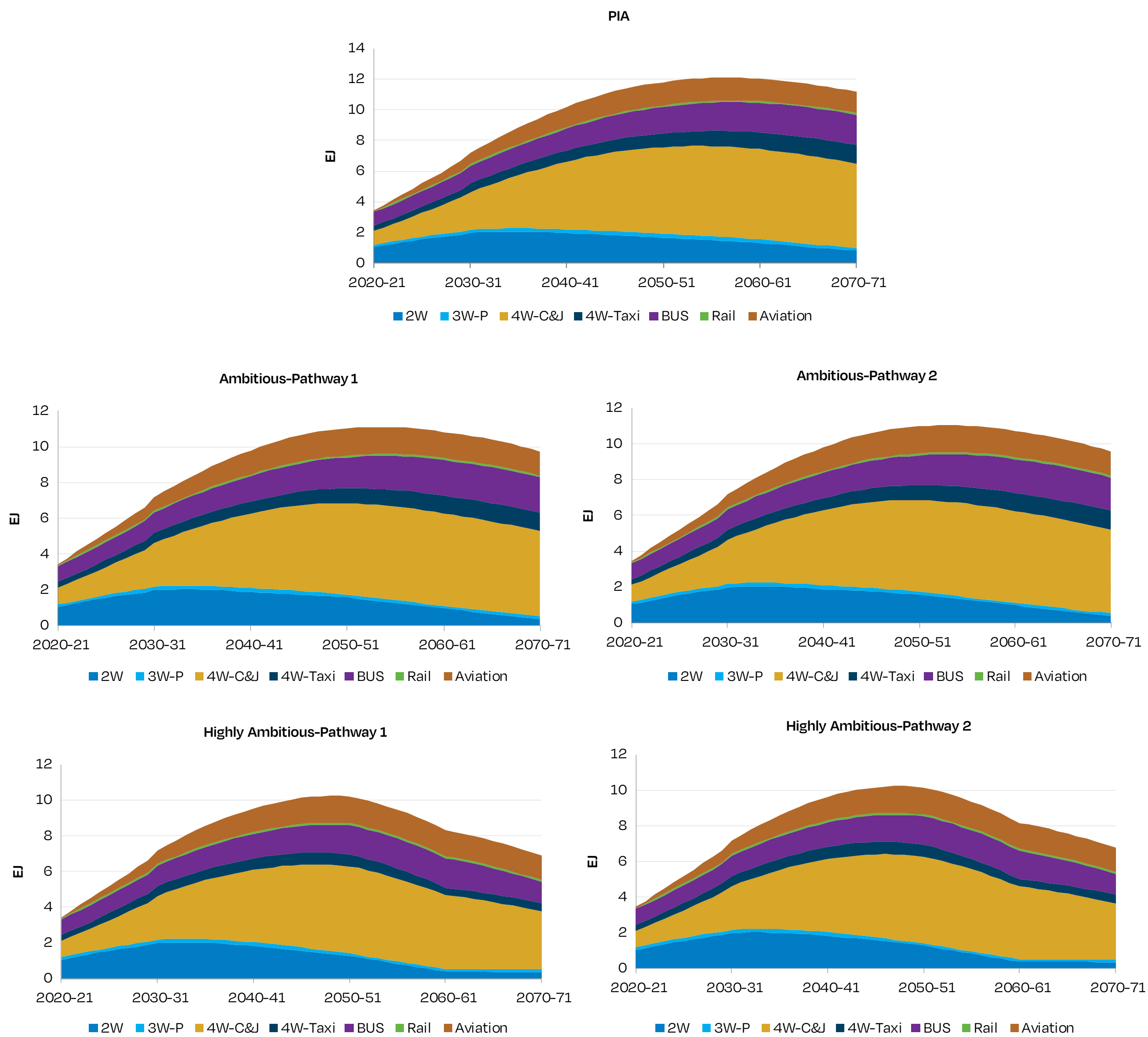
6.3 Energy and Fuel Demand

6.3.1 Passenger Transport

The energy requirements from passenger transport demand under the PIA, Ambitious, and Highly Ambitious scenarios are presented in Figure 6.1.

[58] https://vahan.parivahan.gov.in/vahan4dashboard/vahan/dashboardview.xhtml

Figure 6.1: Energy demand– Passenger transport



Source: TERI

In comparison to the baseline estimates (Figure 5.12), the three scenarios present significant reduction in energy demand from passenger transport (Table 6.4).

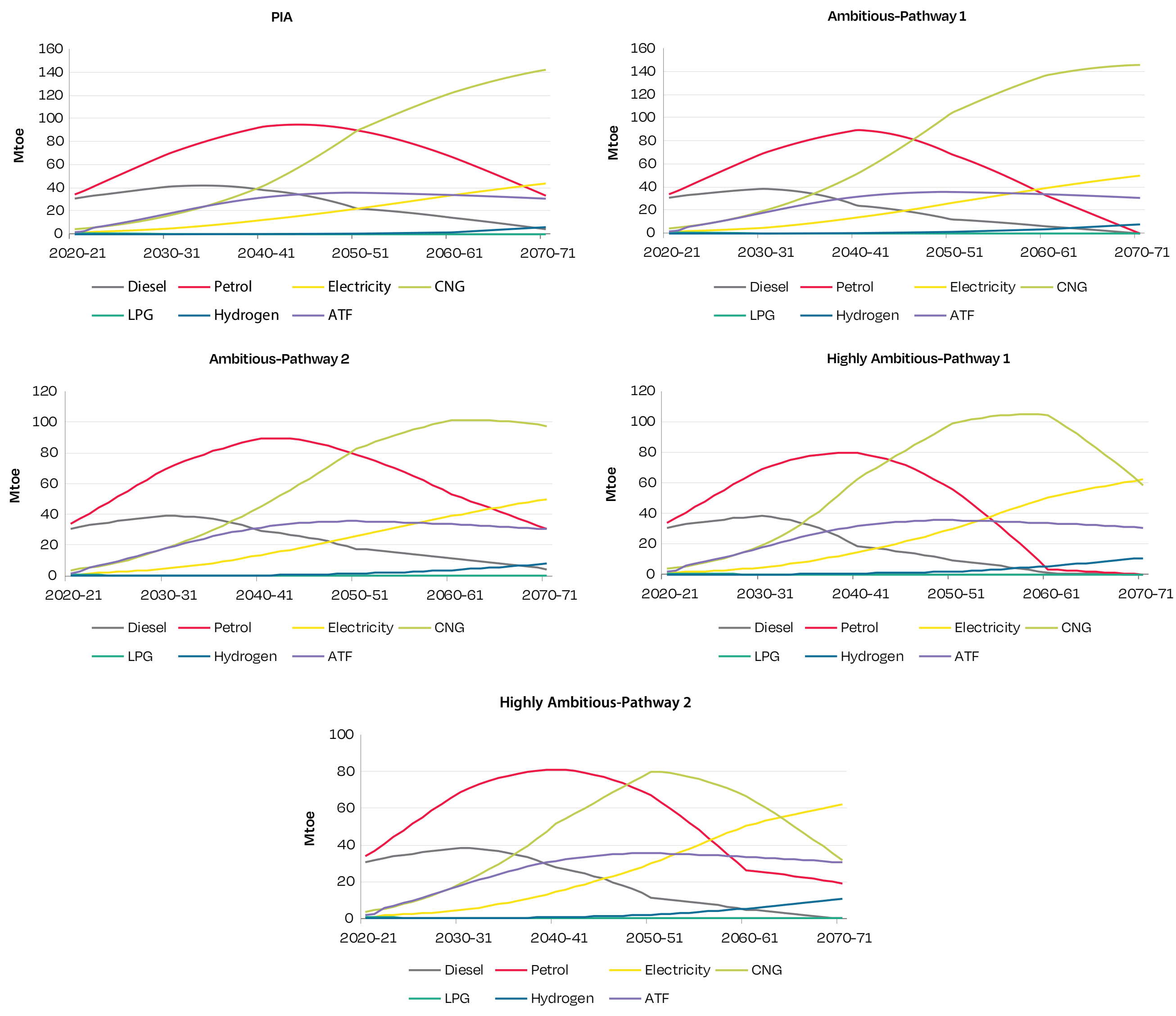
Table 6.4: Passenger transport energy demand– Comparative assessment of scenarios

Years	Energy Demand (EJ)					
	Baseline	PIA	Ambitious-Pathway 1	Ambitious-Pathway 2	Highly Ambitious-Pathway 1	Highly Ambitious-Pathway 2
2020–21	3.44	3.44	3.44	3.44	3.44	3.44
2030–31	7.42	7.20	7.17	7.18	7.17	7.17
2040–41	11.69	10.19	9.77	9.78	9.51	9.61
2050–51	15.01	11.78	11.03	10.97	10.22	10.15
2070–71	17.02	11.15	9.75	9.58	6.88	6.78

Source: TERI

Fuel demand is expected to moderate considerably under the three alternative scenarios, associated with a reduction in demand for petroleum products, but a significant increase for CNG and electricity (Figure 6.2) is expected.

Figure 6.2: Fuel demand– Passenger transport



Source: TERI

In all the scenarios, petrol and diesel demands are expected to reduce, and under the Pathway 1 of both the Ambitious and Highly Ambitious scenarios the demands for these two products are projected to cease to exist in passenger transport by 2070–71. The peak demand for petrol is expected by 2044–45 under PIA at 94.5 Mtoe, whereas the peak of petrol demand is expected to be reached by 2041–42 at 89 Mtoe under the Ambitious scenario (both pathways). The peak for petrol in passenger transport is expected to be achieved between 2039–40 and 2040–41 at 80–81 Mtoe under the Highly Ambitious scenario (the two pathways). Diesel demand is expected to peak by 2034–35 at 42 Mtoe under PIA scenario; however, under the Ambitious and Highly Ambitious scenarios (two pathways for each) it is expected to reach peak by 2030–31 at 38–39 Mtoe.

The scenarios differ considerably in terms of the demand potential of natural gas (CNG) in passenger transport. The visible shift from petroleum products to natural gas is evident under all the scenarios; however, under the highly ambitious scenario (both the pathways) CNG demand reaches its peak (2058–59 under pathway 1 and 2050–51 under pathway 2) at 105 Mtoe and 80 Mtoe under pathways 1 and 2 respectively. Table 6.5 provides the estimated fuel demand potential under the three scenarios.

Table 6.5: Fuel demand in passenger transport– Comparative assessment of scenarios

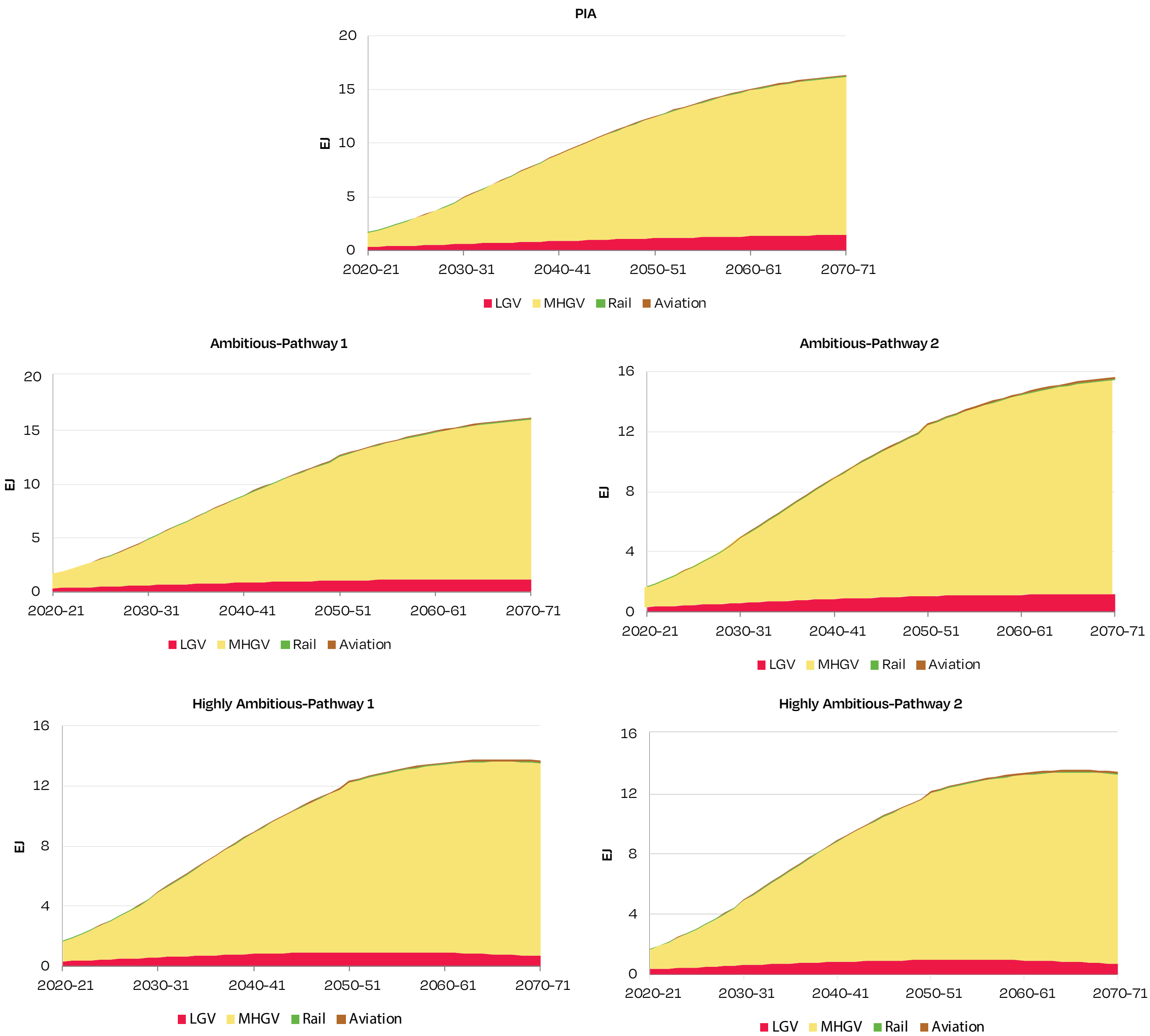
Years	Fuel Demand (Mtoe)					
	Baseline	PIA	Ambitious-Pathway 1	Ambitious-Pathway 2	Highly Ambitious-Pathway 1	Highly Ambitious-Pathway 2
2020–21	71.09	71.09	71.09	71.09	71.09	71.09
2030–31	155.93	148.54	148.68	148.72	148.63	148.63
2040–41	247.65	215.81	209.79	208.92	207.18	206.96
2050–51	320.00	258.61	247.25	241.80	231.09	226.05
2070–71	368.02	258.70	233.45	220.24	162.00	154.36

Source: TERI

6.3.2 Freight Transport

The energy requirements from freight transport demand under the different scenarios are presented in Figure 6.3.

Figure 6.3: Energy demand– Freight transport



Source: TERI

The dominance of MHGV segment will continue and a marginal reduction in energy demand is expected under the two scenarios (Table 6.6).

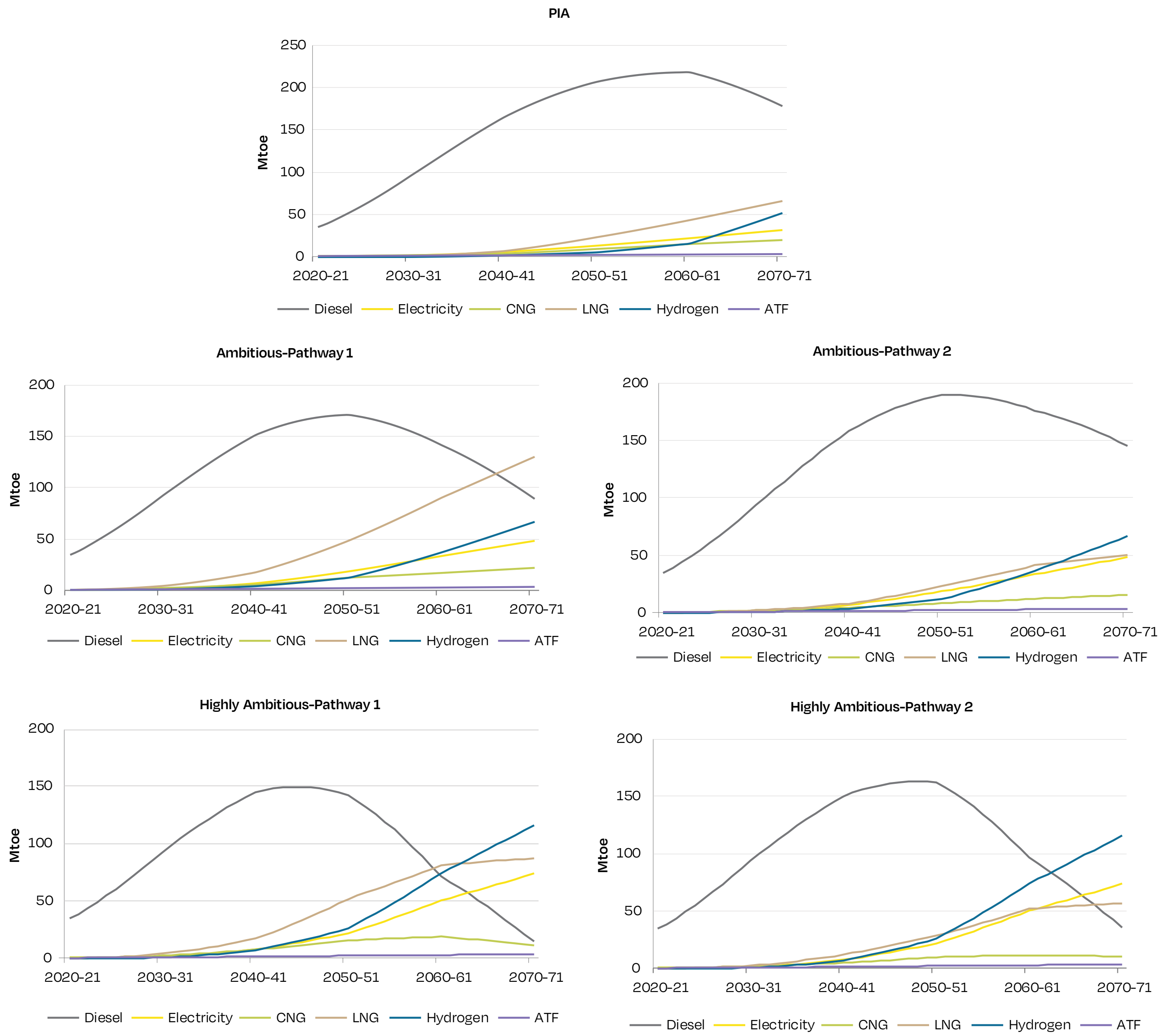
Table 6.6: Freight transport energy demand– Comparative assessment of scenarios

Years	Energy Demand (EJ)					
	Baseline	PIA	Ambitious-Pathway 1	Ambitious-Pathway 2	Highly Ambitious-Pathway 1	Highly Ambitious-Pathway 2
2020-21	1.72	1.72	1.72	1.72	1.72	1.72
2030-31	4.85	4.97	4.99	4.98	4.99	4.98
2040-41	8.94	9.03	9.05	8.96	8.97	8.93
2050-51	12.57	12.54	12.73	12.52	12.34	12.19
2070-71	17.38	16.37	16.24	15.63	13.70	13.51

Source: TERI

Despite the relatively similar energy demand trajectories, fuel demand varies considerably under the three scenarios (Figure 6.4).

Figure 6.4: Fuel demand– Freight transport



Source: TERI

While the diesel demand is expected to peak at 218 Mtoe by 2060–61 in PIA scenario, the peak is expected much earlier by 2050–51 at 171 Mtoe in the pathway 1 and by 2051–51 at 190 Mtoe in the pathway 2 of the Ambitious scenario. Under the Highly Ambitious scenario, diesel demand is expected to peak at 149 Mtoe by 2045–46 under pathway 1 and 163 Mtoe by 2048–49 under pathway 2. A shift from petroleum products to natural gas (CNG and LNG) is prominent in the Ambitious and Highly Ambitious scenarios. Under the Ambitious scenario, natural gas demand is expected to increase till 2070–71 and reach 152 Mtoe under pathway 1 and 66 Mtoe under pathway 2. However, under the Highly Ambitious scenario, natural gas demand is expected to reach 98 Mtoe under pathway 1 and 67 Mtoe under pathway 2 by 2070–71. Under pathway 1 of the Highly Ambitious scenario, natural gas demand is expected to reach its peak at 100 Mtoe by 2064–65. Under the Highly Ambitious scenario (both the pathways), growth in natural gas demand is expected to decelerate in 2050s, mainly owing to increasing adoption of EVs and hydrogen as transportation fuel. Overall fuel demand from freight transport under the three scenarios are presented in Table 6.7.

Table 6.7: Fuel demand in freight transport– Comparative assessment of scenarios

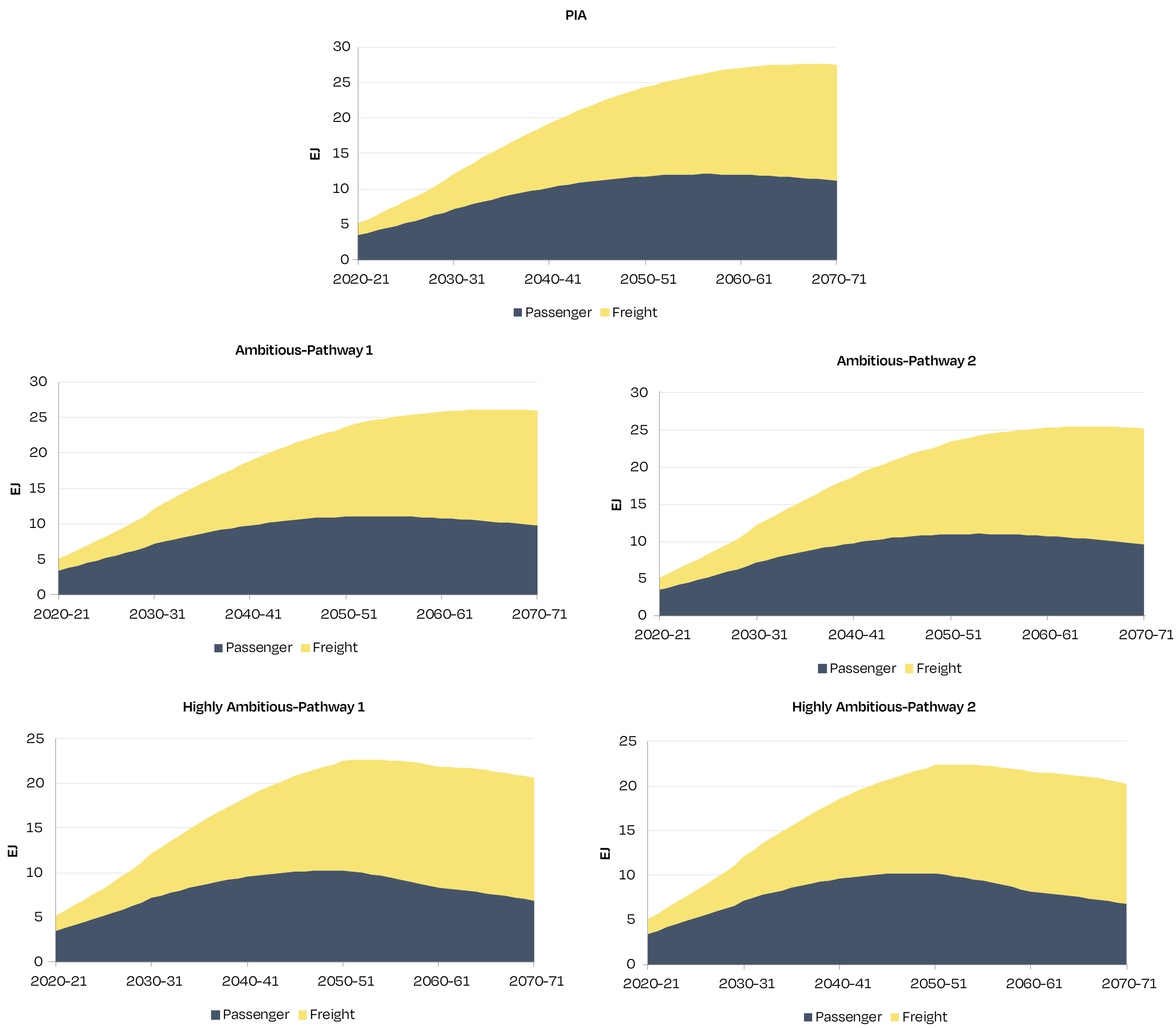
Years	Fuel Demand (Mtoe)					
	Baseline	PIA	Ambitious-Pathway 1	Ambitious-Pathway 2	Highly Ambitious-Pathway 1	Highly Ambitious-Pathway 2
2020-21	35.69	35.69	35.69	35.69	35.69	35.69
2030-31	100.44	100.27	101.33	100.61	101.33	100.75
2040-41	185.35	183.45	186.46	182.75	185.52	183.10
2050-51	261.98	259.11	264.15	254.02	259.21	250.34
2070-71	365.68	349.57	359.72	329.71	305.78	295.56

Source: TERI

6.3.3 Energy Demand

Energy demand from transport is expected to be lower under all the three scenarios compared to the baseline, with expected peak at 28 EJ by 2067–68 under the PIA, between 25-26 EJ by 2065–67 under Ambitious, and between 22-23 EJ by 2052-54 under the Highly Ambitious scenarios. In contrast to the even split of the energy demand between passenger and freight under the baseline scenario projected by 2070–71 (*c.f.* Figure 5.15), the share of passenger transport is expected to fall below 50 percent under all the alternative scenarios by end of 2040s (Figure 6.5).

Figure 6.5: Transport sector energy demand– Passenger vs freight



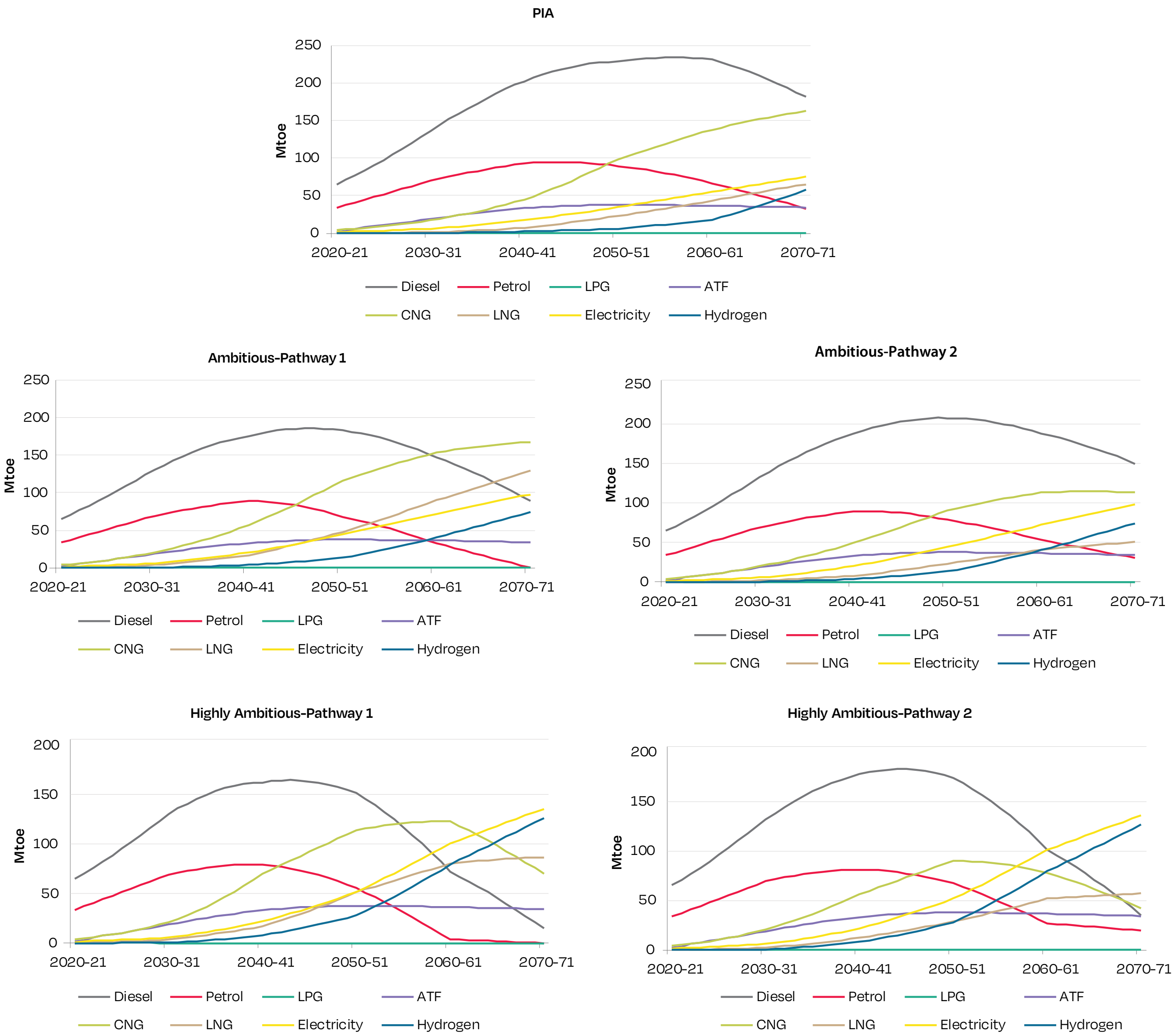
Source: TERI

By 2070–71 the projected shares of passenger transport in total energy demand under PIA, the Ambitious, and the Highly Ambitious scenarios are 41, 38, and 33 percentages respectively.

6.3.4 Fuel Demand

The three scenarios have significant impact on fuel demand and a shift from petroleum (diesel, petrol, LPG, and ATF) to natural gas (CNG and LNG) and non-fossil fuel sources (electricity and hydrogen) is visible under the three scenarios (Figure 6.6).

Figure 6.6: Transport sector– Fuel demand



Source: TERI

Petrol demand is expected to peak at 94 Mtoe by 2044–45 under PIA. Under the Ambitious scenario, petrol demand is expected to reach its peak at 89 Mtoe between 2040–42 under the two pathways, whereas, under the Highly Ambitious scenario the peak is expected at 80-81 Mtoe between 2039-41 under the two pathways. By 2070–71 petrol demand is expected to cease to exist under the pathway 1 of both Ambitious and Highly Ambitious scenarios, as all the petrol vehicles are phased out. Diesel demand is expected to peak at 234 Mtoe by 2056–57 under PIA. However, due to the greater adoption of EVs, hydrogen as fuel, and natural gas, diesel demand under the Ambitious scenario will reach its peak between 186 and 207 Mtoe by 2047–48 and 2049–50 under pathways 1 and 2 respectively. Under the Highly Ambitious scenario, it will reach its peak at 165 Mtoe by 2043–44 under pathway 1 and 183 Mtoe by 2044–45 under pathway 2.

Consequently, associated with the fall in demand for petroleum products (petrol, diesel, LPG, and ATF), demand for natural gas (CNG and LNG) is expected to grow considerably. Under the PIA scenario, natural gas demand for transportation is expected to increase to 228 Mtoe by

2070–71. Under the Ambitious scenario, natural gas demand by 2070–71 is expected to increase to 297 Mtoe under pathway 1 and 163 Mtoe under pathway 2. The impact of higher degree of electrification and use of hydrogen as fuel under the Highly Ambitious scenario is evident from the demand for natural gas. Under both the pathways natural gas demand is expected to reach peak at 204 and 130 Mtoe (under pathways 1 and 2, respectively) by 2060–61 and fall afterwards.

The demands for different types of fuel are presented in Table 6.8 under the three scenarios.

Table 6.8: Projected fuel demand (in Mtoe) in transport sector– Comparison of scenarios

Scenarios	Years	Fuel Demand (Mtoe)								
		Diesel	Petrol	LPG	ATF	CNG	LNG	Elect.	Hydrogen	TOTAL
2020-21		65	34	1	2	4	0	1	0	107
Baseline	2030-31	146	75	1	19	12	1	3	0	256
	2050-51	337	133	0	40	53	9	10	0	582
	2070-71	411	127	0	42	102	28	24	0	734
PIA	2030-31	136	69	0	19	17	1	6	0	249
	2050-51	228	89	0	38	99	23	35	6	518
	2070-71	181	33	0	34	163	65	75	57	608
Ambitious-Pathway 1	2030-31	131	69	0	19	21	4	6	0	250
	2050-51	183	68	0	38	116	48	45	13	511
	2070-71	89	0	0	34	168	130	98	75	593
Highly Ambitious-Pathway 1	2030-31	131	69	0	19	21	4	6	0	250
	2050-51	151	56	0	38	114	52	52	28	490
	2070-71	15	0	0	34	70	87	136	127	468
Ambitious-Pathway 2	2030-31	133	69	0	19	20	2	6	0	249
	2050-51	207	79	0	38	91	23	45	13	496
	2070-71	150	30	0	34	113	50	98	75	550
Highly Ambitious-Pathway 2	2030-31	132	69	0	19	21	2	6	0	249
	2050-51	173	67	0	38	90	29	52	28	476
	2070-71	35	19	0	34	42	57	136	127	450

Note: Elect.- Electricity.

Source: TERI

In 2020–21, petroleum product demand as transportation fuel (petrol, diesel, LPG, and ATF) was estimated at 102 Mtoe, whereas the natural gas demand as transportation fuel (CNG and LNG) was estimated at 4 Mtoe. Petroleum product demand is expected to reach 241 Mtoe under the baseline scenario by 2030–31, whereas the natural gas demand is expected to reach 13 Mtoe. The demand for petroleum products and natural gas are expected to further increase to 510 Mtoe and 62 Mtoe respectively by 2050–51, and 580 Mtoe and 130 Mtoe respectively by 2070–71. Under the PIA scenario, the petroleum product demands are expected to reach 225 Mtoe by 2030–31, 355 Mtoe by 2050–51, and 248 Mtoe by 2070–71. Correspondingly, the demand for natural gas is expected to increase to 18 Mtoe by 2030–31, 122 Mtoe by 2050–51, and 228 Mtoe by 2070–71.

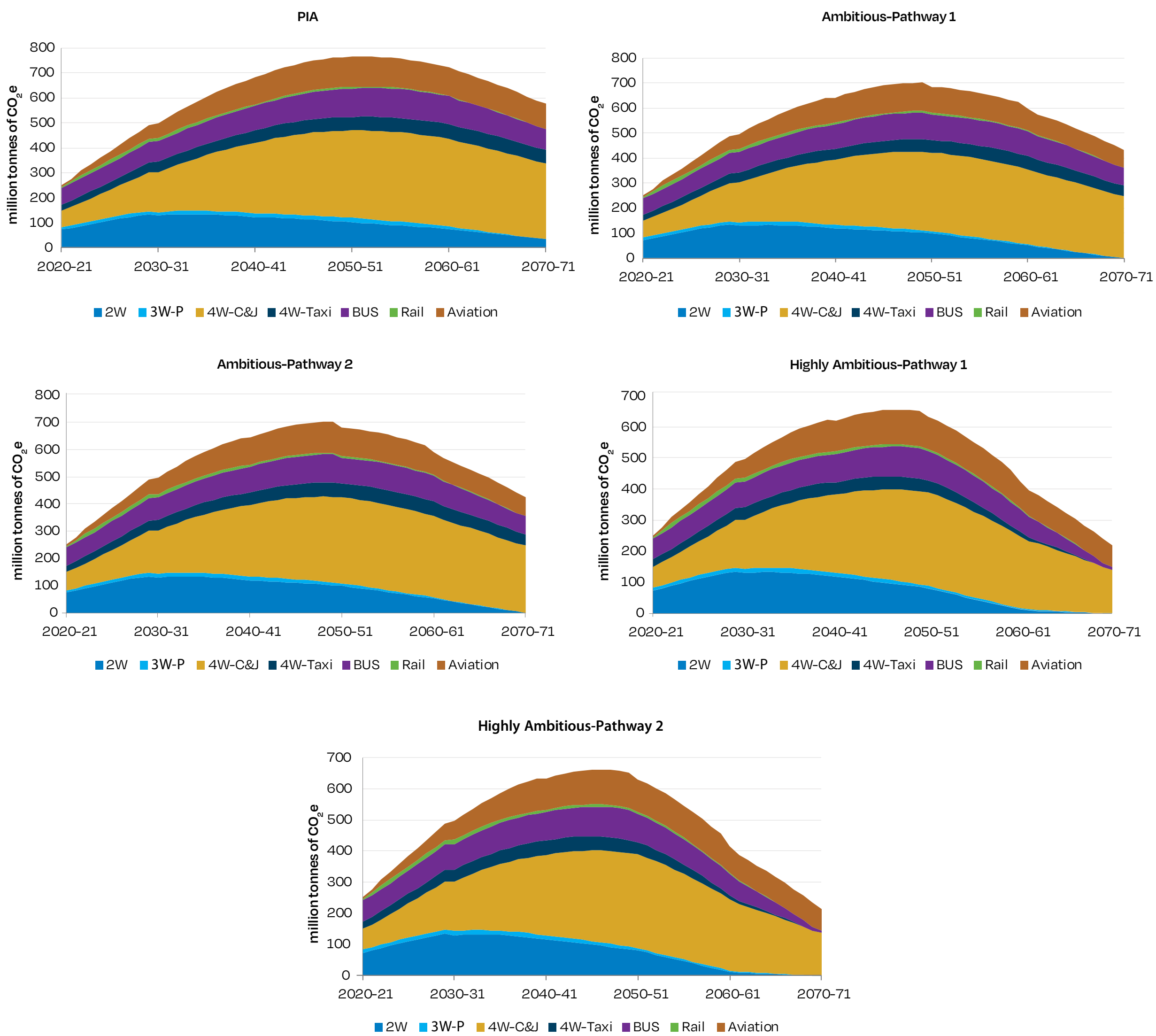
Under the Ambitious scenario, petroleum product demands are expected to reach 219 (221) Mtoe under pathway 1 (pathway 2) by 2030–31, 289 (324) Mtoe under pathway 1 (pathway 2) by 2050–51, and 123 (214) Mtoe under pathway 1 (pathway 2) by 2070–71. Corresponding natural gas demands are expected to reach 25 (22) Mtoe under pathway 1 (pathway 2) by 2030–31, 164 (114) Mtoe under pathway 1 (pathway 2) by 2050–51, and 298 (163) Mtoe under pathway 1 (pathway 2) by 2070–71.

The impact of considerable electrification of transport and use of hydrogen as fuel under the Highly Ambitious scenario is evident from the reduced fossil fuel (petroleum products and natural gas) demand. Demands for petroleum product are expected to reach 219 (220) Mtoe under pathway 1 (pathway 2) by 2030–31, 245 (278) Mtoe under pathway 1 (pathway 2) by 2050–51, and 49 (89) Mtoe under pathway 1 (pathway 2) by 2070–71. Correspondingly, the demands for natural gas are expected to reach 25 (23) Mtoe under pathway 1 (pathway 2) by 2030–31, 166 (119) under pathway 1 (pathway 2) by 2050–51, and 157 (99) Mtoe under pathway 1 (pathway 2) by 2070–71.

6.4 Well-to-wheel GHG Emissions

The three scenarios developed in the report have significant GHG emission (well-to-wheel, WTW) reduction potential for passenger transport, based on increasing adoption of EVs and CNG vehicles (Figure 6.7). The blending of biofuels and penetration of vehicles using green hydrogen as fuel further reduce emissions, as compared to baseline scenario.

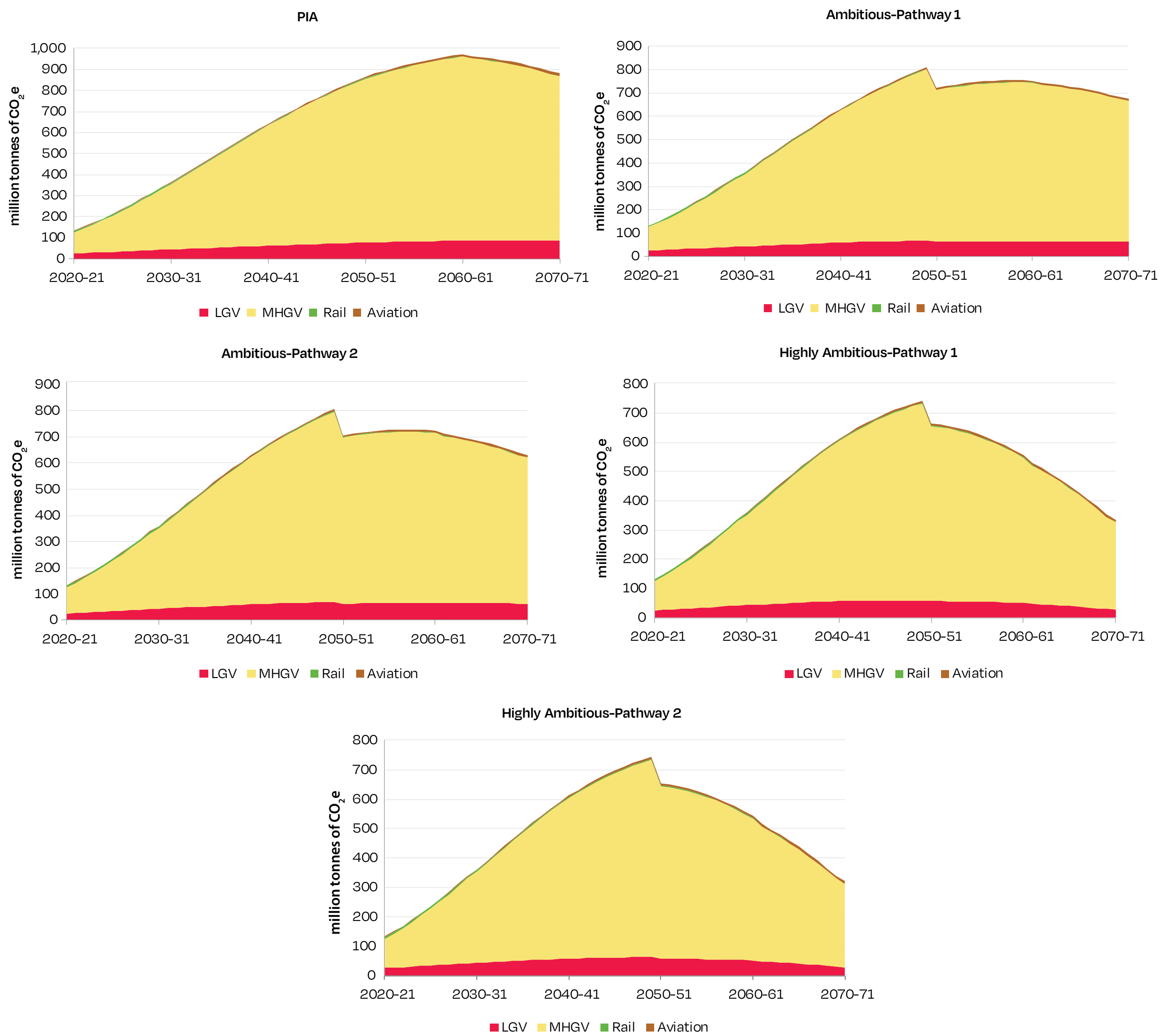
Figure 6.7: GHG emissions from passenger transport



Source: TERI

The MHGV segment is considered as 'the' hard-to-abate sector in road transport, where the potential for electrification is much restricted as compared to natural gas or hydrogen as fuel. However, unlike the expanding GHG emissions from freight transport in baseline scenario, it is expected to decarbonise considerably under the three alternative scenarios (Figure 6.8).

Figure 6.8: GHG emissions from freight transport



Note: The 'kink' in the Ambitious and Highly Ambitious scenarios are owing to the increase in biodiesel blending from 5 percent to 10 percent in 2050–51.

Source: TERI

In line with the shifting pattern of energy demand, the split of GHG emission between passenger and freight transport is poised to shift towards freight transport starting early-2040s under all the scenarios. It is expected that the share of passenger transport in total transport sector emission will reduce from the present 65 percent to almost 40 percent by 2070–71, mostly owing to the significantly higher degree of electrification of passenger transport. The peak GHG emission is expected to reach 1,696 million tonnes of CO_2e by 2059–60 under the PIA scenario. Under the Ambitious scenario the peak of GHG emission is estimated to range between 1,413 and 1,392 million tonnes of CO_2e by 2052–54 (depending upon the two pathways), while under the Highly Ambitious scenario GHG emission is estimated to reach its peak between 1,395 and 1,396 million tonnes of CO_2e by 2049–50 (depending upon the two pathways).

GHG emissions from different modes of transport are listed in Table 6.9. The Highly Ambitious scenario (both the pathways) has significant emission abatement impact, as the GHG emission estimated for 2070–71 (ranging between 535 and 553 million tonnes of CO_2e) is expected to come down to a level which is similar to the baseline GHG emission (529 million tonnes of CO_2e) estimated for 2023–24.

Table 6.9: Projections of WTW GHG emissions from transportation in India

Scenario	Year	GHG Emission (million tonnes of CO_2e)									
		Road							Rail	Aviation	ALL
		2W	3W-P	4W	BUS	LGV	MHGV	Total			
2020-21		72	10	91	67	26	100	367	11	7	384
Baseline	2030-31	150	16	220	84	46	316	831	19	64	915
	2040-41	175	23	418	108	68	600	1,392	10	116	1,518
	2050-51	165	30	603	138	88	846	1,870	9	137	2,016
	2070-71	112	43	689	170	111	1,147	2,272	0	144	2,416
PIA	2030-31	129	14	201	82	44	309	779	19	63	861
	2040-41	123	15	331	98	62	570	1,199	10	111	1,321
	2050-51	103	18	402	114	77	779	1,493	9	127	1,630
	2070-71	34	0	357	82	88	781	1,343	0	115	1,458
Ambitious-Pathway 1	2030-31	129	14	198	82	43	308	775	19	63	857
	2040-41	119	14	305	96	60	563	1,157	10	105	1,272
	2050-51	99	10	364	101	63	649	1,286	9	112	1,407
	2070-71	0	0	289	73	63	604	1,029	0	78	1,107
Highly Ambitious-Pathway 1	2030-31	129	14	198	82	43	308	774	19	63	857
	2040-41	116	13	293	92	57	548	1,118	10	105	1,234
	2050-51	80	7	341	93	57	598	1,177	9	112	1,298
	2070-71	0	0	141	8	28	299	476	0	78	553
Ambitious-Pathway 2	2030-31	129	14	198	82	43	308	775	19	63	858
	2040-41	119	14	309	96	60	561	1,159	10	105	1,274
	2050-51	99	10	366	96	63	634	1,268	9	112	1,389
	2070-71	0	0	288	66	63	559	977	0	78	1,055
Highly Ambitious-Pathway 2	2030-31	129	14	198	82	43	308	774	19	63	857
	2040-41	116	13	304	92	58	547	1,130	10	105	1,245
	2050-51	80	7	342	90	58	586	1,163	9	112	1,284
	2070-71	0	0	136	8	28	285	457	0	78	535

Source: TERI

Under all the scenarios, road freight sector is expected to dominate. The share of road freight sector in total emission is projected to increase to around 60 percent by 2070–71 under the alternative scenarios (PIA and ambitious) from a modest 33 percent share in 2020–21. Such increase is attributable to the faster adoption of non-fossil fuel in passenger transport sector compared to the freight segment.

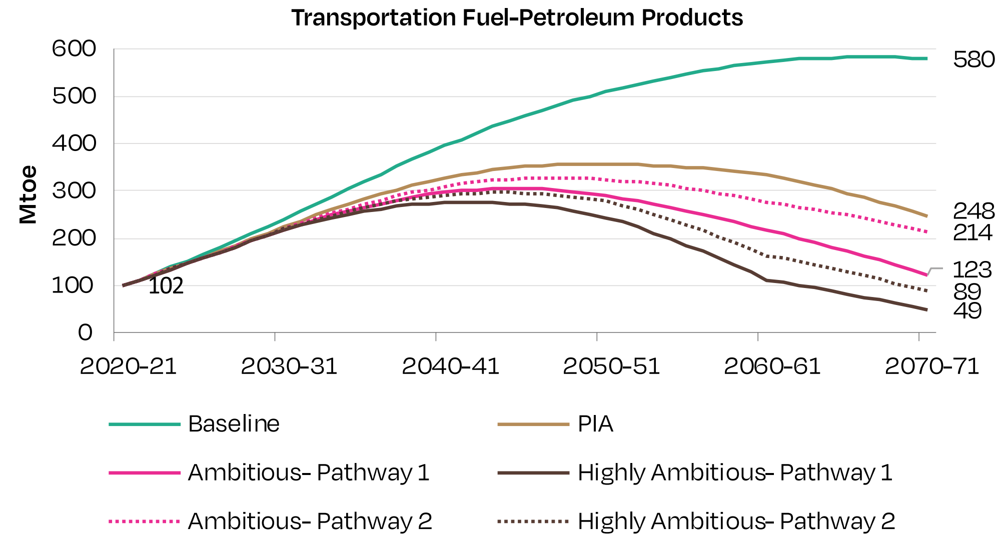
6.5 Implications of the Alternative Scenarios for Transport Sector in India

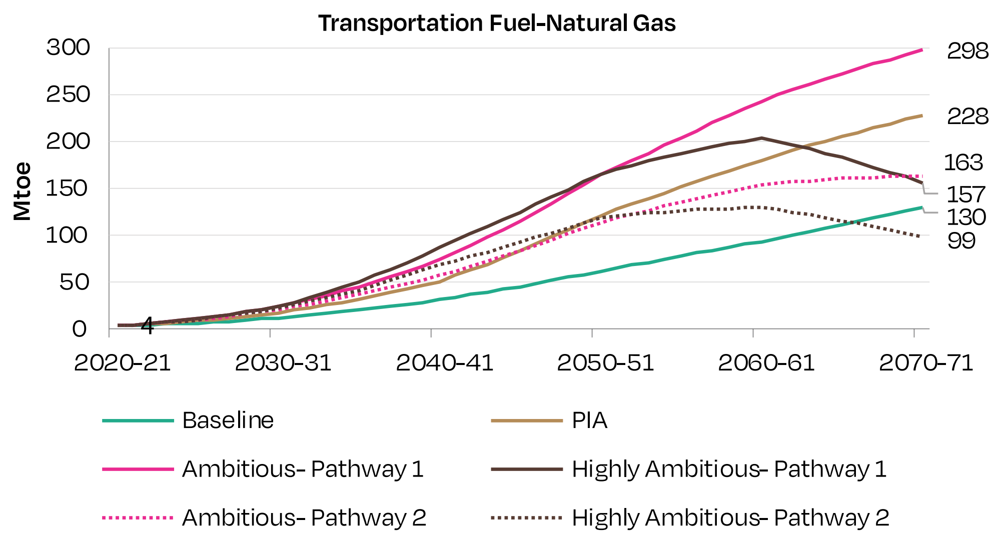
The three scenarios developed as low-carbon alternatives to the baseline trajectory in India assumed varying degrees of penetration of alternative fuel vehicles, increased fuel efficiencies, and biofuel blending targets compared to the baseline scenario. Additionally, phased reduction in fossil fuels in power generation has also been considered. These provide significant GHG emission abatement potential and changes in the fuel demand.

6.5.1 Fuel Demand

Demands for petroleum products (petrol, diesel, LPG, and ATF) and natural gas (CNG and LNG) as transportation fuels under the baseline and three alternative scenarios (PIA, Ambitious, and Highly Ambitious) are presented in Figure 6.9.

Figure 6.9: Petroleum product and natural gas demand for transport





Note: Petroleum products include petrol, diesel, LPG and ATF; natural gas includes CNG and LNG; the values presented in the diagram include biofuels in respective segments.

Source: TERI

Compared to the baseline estimates for respective years, PIA pathway is expected to reduce petroleum product demand by 7 percent in 2030–31, 30 percent in 2050–51, and 57 percent by 2070–71. The impact of the ambitious pathway is much greater, 9 (8) percent reduction under pathway 1 (pathway 2) by 2030–31, 43 (52) percent reduction under pathway 1 (pathway 2) by 2050–51, and 79 (63) percent reduction under pathway 1 (pathway 2) by 2070–71. The Highly Ambitious scenario has the highest impact on reduction in petroleum product demand– a reduction of 9 percent under both the pathways by 2030–31, 52 (45) percent under pathway 1 (pathway 2) by 2050–51, and 92 (85) percent reduction under pathway 1 (pathway 2) by 2070–71, when compared to baseline demand for respective years. Under the alternative scenarios, the peak petroleum product demand is projected to be reached in the 2040s, highest at 357 Mtoe under PIA and the lowest at 297 Mtoe under pathway 2 of the Highly Ambitious scenario.

The alternative scenarios consider significant increase in use of natural gas in transportation. Compared to the baseline estimates of respective years, under PIA the natural gas demand is expected to increase by 45 percent by 2030–31, 96 percent by 2050–51, and 75 percent by 2070–71. Under the Ambitious scenario, natural gas demand is expected to increase by 99 (76) percent under pathway 1 (pathway 2) by 2030–31, 164 (83) percent under pathway 1 (pathway 2) by 2050–51, and 129 (26) percent under pathway 1 (pathway 2) by 2070–71. Under the Highly Ambitious scenario, natural gas demand is expected to increase 99 (85) percent under pathway 1 (pathway 2) by 2030–31, 167 (91) percent increase under pathway 1 (pathway 2) by 2050–51, and 20 percent increase under pathway 1 but a 24 percent reduction under pathway 2, when compared to baseline estimates.

Fossil fuel demand in transportation (petrol, diesel, LPG, ATF, CNG, and LNG) is expected to grow till almost 2060–61 under the PIA and Ambitious scenarios. However, the Highly Ambitious scenario has considerable impact on demand reduction after the peak demand (411 Mtoe under pathway 1 and 397 Mtoe under pathway 2) is achieved by 2050–51 (Figure 6.10). Under the Highly Ambitious scenario petroleum product demand for transport is expected to fall below the 2030–31 level. Concurrently with the fossil fuel demand trajectory for transport sector, the demand for non-fossil fuels (electricity and hydrogen) is expected to increase significantly under the three alternative scenarios, owing to increasing adoption of EVs and hydrogen as fuel (Figure 6.10).

Restructuring of fossil fuel demand in transport

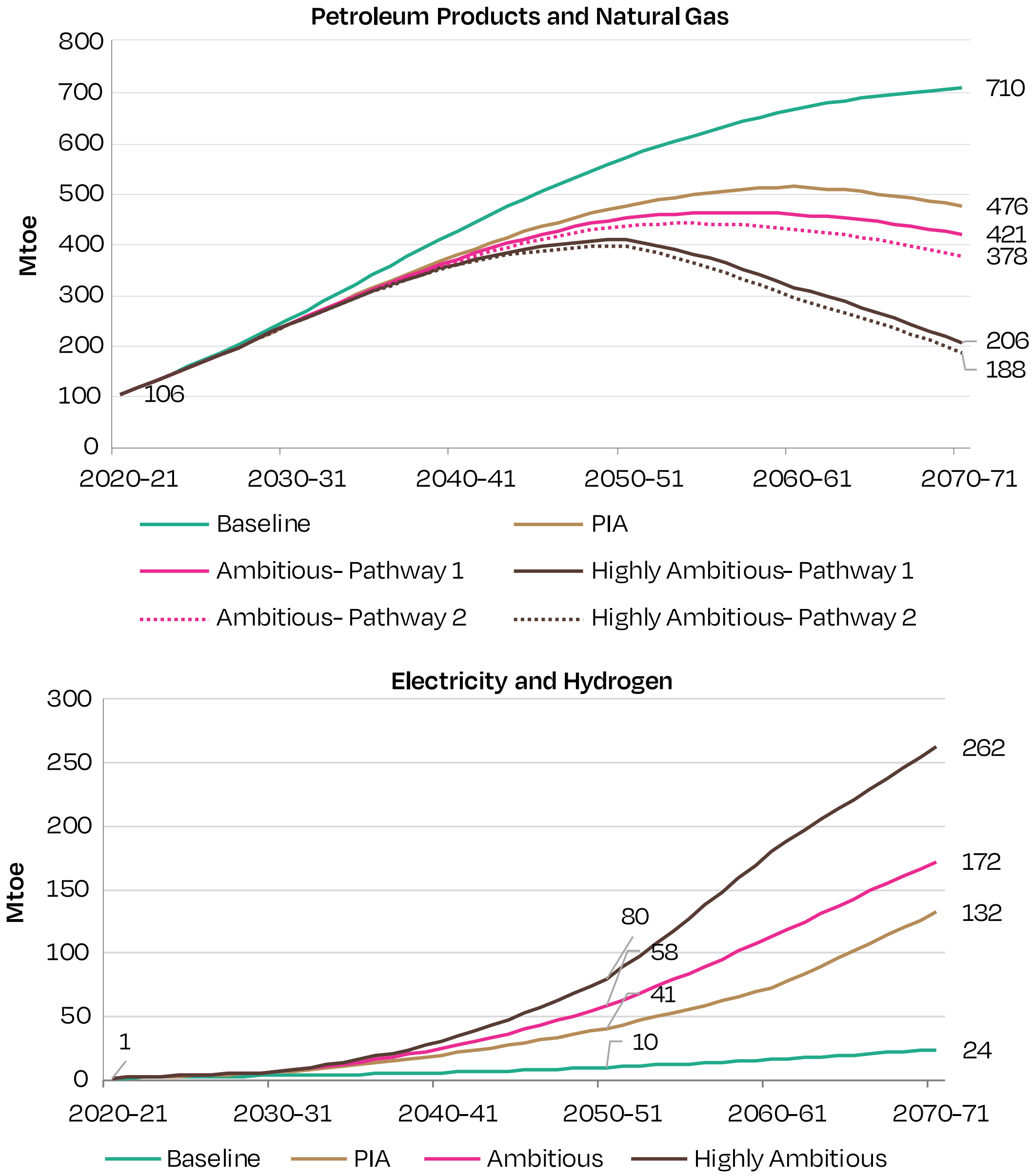
A visible shift from petroleum products to natural gas as transportation fuel.

Dependence on fossil fuels for transportation purposes will continue but will largely be substituted by electricity and hydrogen.

The Highly Ambitious scenario hold great potential for decarbonisation of the sector.

The adoption path for hydrogen as fuel in transport sector is likely to start with low-cost gray hydrogen, to blue hydrogen, and then shift to the costly green hydrogen.

Figure 6.10: Fuel demand in transport- Fossil fuel vs. non-fossil fuel



Source: TERI

The three alternative scenarios consider different biofuel blending percentages at different points of time. Biofuels are mixed with the petroleum products (petrol, diesel, and ATF) and CNG, hence, energy and fuel demands discussed so far in the report consider the blended fuels. However, after the volume/mass of biofuels is factored out, the demand for unblended petroleum products and CNG can be obtained. Table 6.10 presents the petroleum and natural gas demand after the biofuels are factored out. It also lists the requirements of hydrogen, LNG, and electricity under the different scenarios. Only green hydrogen has been considered in the report; however, the adoption may start with grey hydrogen owing to its cheap cost of production, followed by use of blue hydrogen, and then shift to green hydrogen when the cost of production reduces.[59]

[59] https://kpmg.com/be/en/home/insights/2021/03/eng-the-hydrogen-trajectory.html

Table 6.10: Fuel demand– Transport sector

Scenario	Year	Fuel Demand						
		Petrol	Diesel	ATF	CNG	LNG	Hydrogen	Electricity
		Million Tonnes						Terawatt-hour
2020-21		29	63	2	3	0	0	11
Baseline	2030-31	65	140	18	10	0.4	0	37
	2040-41	96	239	32	23	2.4	0	65
	2050-51	114	323	38	43	7.4	0	115
	2070-71	109	394	39	82	22.8	0	275
PIA	2030-31	53	124	17	13	0.9	0	68
	2040-41	71	184	30	34	5.6	0.8	203
	2050-51	68	208	35	75	18.6	2.1	402
	2070-71	25	165	31	124	52.6	19.9	871
Ambitious-Pathway 1	2030-31	53	119	17	16	3.1	0.2	68
	2040-41	68	160	28	44	13.8	1.4	238
	2050-51	52	158	28	84	38.7	4.6	518
	2070-71	0	77	16	115	104.6	26.0	1,138
Highly Ambitious-Pathway 1	2030-31	53	119	17	16	3.1	0.2	67
	2040-41	61	148	28	54	13.8	2.8	255
	2050-51	42	131	28	83	41.6	9.7	602
	2070-71	0	13	16	48	70.0	44.1	1,578
Ambitious-Pathway 2	2030-31	53	121	17	15	1.6	0.2	68
	2040-41	68	171	28	38	6.4	1.4	238
	2050-51	60	179	28	66	18.7	4.6	518
	2070-71	23	129	16	77	40.6	26.0	1,138
Highly Ambitious-Pathway 2	2030-31	53	120	17	16	1.9	0.2	67
	2040-41	62	162	28	43	9.7	2.8	255
	2050-51	51	150	28	65	23.0	9.7	602
	2070-71	15	30	16	29	45.7	44.1	1,578

Source: TERI

The three scenarios provide significant opportunities for reduction in demand for petroleum products in comparison to the baseline demand for respective years. Consequently, increased use of natural gas also provides expanding opportunity, portraying a substitution from primarily a petroleum-based to a primarily gas-based transportation. These opportunities are presented in Table 6.11. Only under the pathway 2 of the Highly Ambitious scenario natural gas demand is expected to be 29 percent lower than corresponding baseline demand by 2070–71.

Table 6.11: Comparative assessment of decarbonising pathways on fossil fuel demand

Scenarios	Years	Decline in Demand Compared to Baseline (%)			Increase in Demand Compared to Baseline (%)
		Petrol	Diesel	ATF	Natural Gas
PIA	2030-31	18	11	2	38
	2040-41	27	23	5	57
	2050-51	40	36	7	88
	2070-71	77	58	20	69
Ambitious- Pathway 1	2030-31	19	15	2	90
	2040-41	29	33	12	127
	2050-51	54	51	24	145
	2070-71	100	80	59	109
Highly Ambitious- Pathway 1	2030-31	19	15	2	90
	2040-41	37	38	12	167
	2050-51	63	60	24	148
	2070-71	100	97	59	12
Ambitious- Pathway 2	2030-31	18	13	2	68
	2040-41	29	29	12	76
	2050-51	47	45	24	69
	2070-71	79	67	59	13
Highly Ambitious- Pathway 2	2030-31	19	14	2	76
	2040-41	36	32	12	109
	2050-51	55	54	24	76
	2070-71	87	92	59	-29

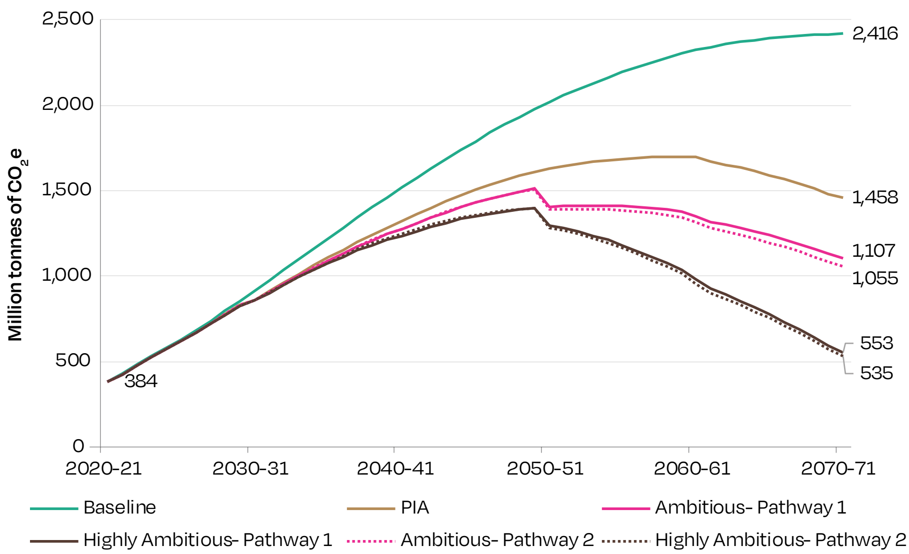
Note: Only the unblended fuels are considered (ethanol, biodiesel, SAF, and CBG are not included).

Source: TERI

6.5.2 Well-to-wheel GHG Emission

The alternative scenarios carry immense potential for WTW GHG emission reduction from transport compared to the baseline projection (Figure 6.11).

Figure 6.11: WTW GHG emission abatement under the scenarios



Source: TERI

Table 6.12 presents the GHG emission abatement potential of the three alternative scenarios over the baseline scenario at different timepoints.

Table 6.12: GHG emission abatement

Years	Reduction (%) in GHG Emission Under		
	PIA over Baseline	Ambitious over Baseline	Highly Ambitious over Baseline
2030–31	6	6	6
2040–41	13	16	18-19
2050–51	19	30-31	36
2070–71	40	54-56	77-78

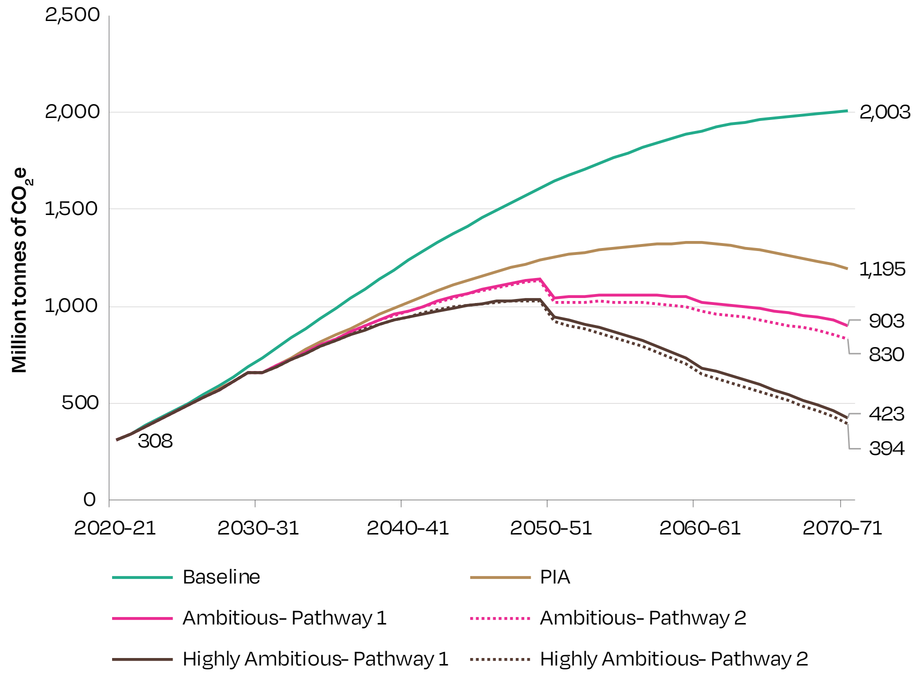
Note: The range in some of the cases indicate the two values under the pathways 1 and 2.

Source: TERI

6.5.3 Tank-to-wheel GHG Emission

WTW emissions capture the overall GHG emission impact of the transport sector including the direct (operational/tank-to-wheel) and indirect (well-to-tank) impact of the vehicle use. This section highlights the impact of GHG emissions from transport considering only the direct use of the vehicles. Vehicles using electricity and hydrogen as fuel have zero tank-to-wheel (TTW) GHG emissions, and SAF blending has significant emission reduction potential for aviation sector.[60] TTW GHG emission is expected to fall considerably due to the adoption of the Ambitious and Highly Ambitious scenarios compared to the baseline (Figure 6.12). The Highly Ambitious scenario can significantly reduce TTW emission and has the potential to reduce the GHG emission than the 2023-24 level (414 million tonnes of CO_2e).

Figure 6.12: TTW GHG emissions under different scenarios



Source: TERI

[60] TTW for electric vehicles correspond to battery to wheel and for railways it corresponds to overhead wire to wheel.

The TTW GHG emission corresponding to the baseline and the three alternative scenarios, and the emission reduction potentials over the baseline are presented in Table 6.13. Compared to the WTW emissions, the alternative scenarios provide higher emission abatement over baseline when emissions are measured as TTW.

Table 6.13: TTW GHG emission abatement potential

Years	TTW GHG Emission (million tonnes of CO_2e)						Emission Reduction (%)		
	Baseline	PIA	Ambitious-P1	Ambitious-P2	HA- P1	HA- P2	PIA over Baseline	Ambitious over Baseline	HA over Baseline
2030–31	1,236	1,019	974	972	942	948	10	11	11
2040–41	1,643	1,251	1,043	1,017	941	918	18	21	23-24
2050–51	2,003	1,195	903	830	423	394	24	37-38	43-44
2070–71	735	659	656	656	656	656	40	55-59	79-80

Note: HA- Highly Ambitious; P1- Pathway 1; P2- Pathway 2; Emission reduction potentials for Ambitious and HA scenarios represent the reduction under both the pathways 1 and 2.

Source: TERI

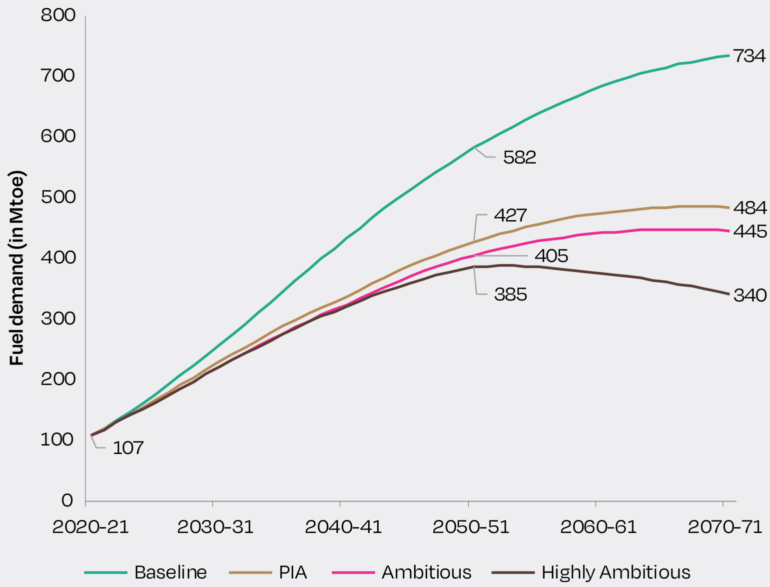
As a result of greater adoption of electric vehicles in passenger vehicle segment, conversion of diesel traction to electric in railways, and aggressive SAF blending with ATF, the dominance of the trucking sector (LGV and MHGV) increases with adoption of the alternative scenarios, compared to the baseline.

Box 2: The Pivotal Role of Railways in GHG Emission Reduction

The share of Indian Railways (IR) in overall freight transportation has been declining steadily since independence, and presently falling below 30 percent of freight movement (measured in BTKM). It is worthwhile mentioning that IR has succeeded in expanding freight loading but has been outperformed by the road freight segment. In the modelling exercise freight demand was estimated in a bottom-up method for road, railways, and aviation. Total passenger and freight transport demands are the aggregates of the three modes. Railways continue the falling trend in its freight and passenger share as legacy of historical trends. The pathways considered in the report are primarily based on fuel technological changes, fuel efficiency improvements, and increasing blending of biofuels. In consonance with the National Rail Plan for 2030, the Ministry of Railways has undertaken several initiatives to increase share of IR (TERI, 2023) to 45 percent of freight transport by 2030.

To accommodate the possibility of expanding share of railways in freight transportation under the TERI-TptM results, two modifications were made to the PIA, Ambitious/Highly Ambitious scenarios. Under the modified PIA scenario, it was assumed that railways reach a share of 35 percent by 2030–31, 45 percent by 2040–41, and remains at that level thereafter. Under the modified Ambitious and Highly Ambitious scenarios, it is assumed that railways reach the target 45 percent share by 2030–31, 50 percent by 2040–41, and remains at that level thereafter. Under both the modifications it is assumed that the shift of freight transportation to railways will occur from the MHGV segment. The reductions in fuel demand from the transport sector under the modifications are indicated in Figure B2.1. As an example, only the pathway 1 for Ambitious and Highly Ambitious scenarios are considered.

Figure B2.1: Fuel demand under rail freight share adjusted scenarios

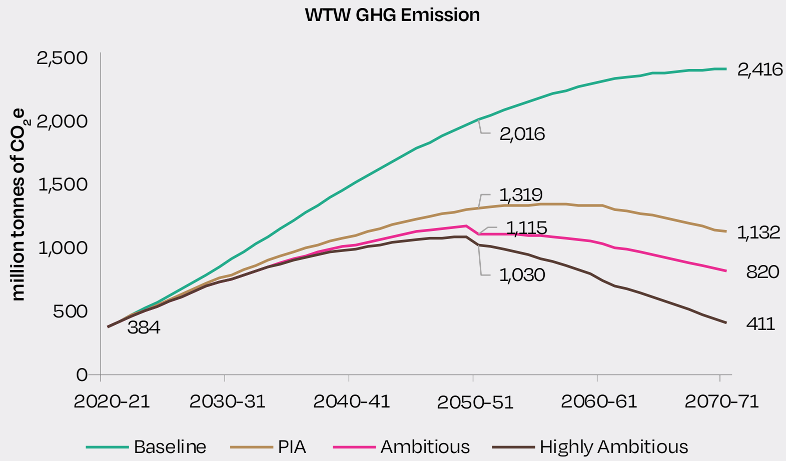


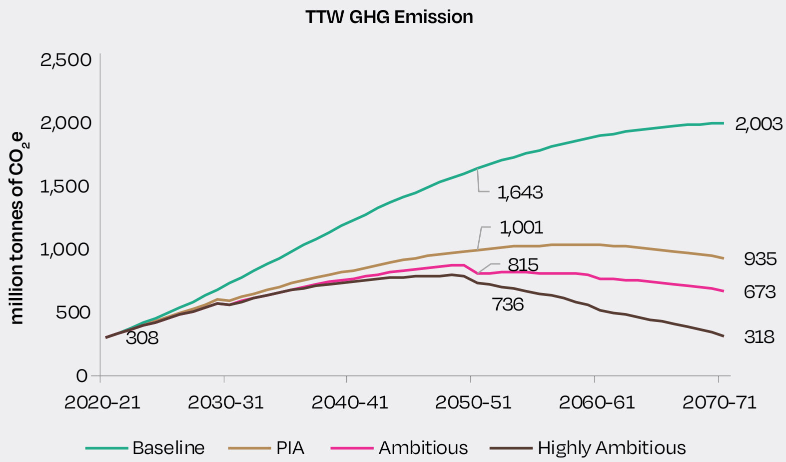
Source: TERI

These adjustments reduce fuel demand considerably, under the modified PIA it reduces from 608 (*c.f.* Table 6.8) to 484 Mtoe, under the modified Ambitious scenario it reduces from 593 (*c.f.* Table 6.8) to 445 Mtoe, and under the modified Highly Ambitious scenario it reduces from 468 Mtoe from 340 Mtoe by 2070–71.

Increasing the share of railways in overall freight transportation has clear GHG emission abatement impacts as indicated in Figure B2.2.

Figure B2.2: GHG emission impact of expanding share of railways in freight





Source: TERI

GHG emissions measured under both WTW and TTW classifications show considerable reduction potential under the modifications to the PIA and ambitious scenarios. WTW emissions reduce from 1,458 (*c.f.* Figure 6.11) to 1,132 million tonnes of CO_2e under the modified PIA scenario, from 1,107 (*c.f.* Figure 6.11) to 820 million tonnes of CO_2e under the modified Ambitious scenarios, and 553 to 411 million tonnes of CO_2e by 2070–71. Consequently, TTW emissions reduce from 1,195 (*c.f.* Figure 6.12) to 935 million tonnes of CO_2e under the modified PIA, from 903 (*c.f.* Figure 6.12) to 673 million tonnes of CO_2e under the modified Ambitious, and 423 to 318 million tonnes of CO_2e under the Highly Ambitious scenarios by 2070–71.

7

Coastal Shipping: A Vision for 2030-31

Coastal shipping in India accounted for 5 percent of the market share of the total freight demand in India in 2017–18 (Ministry of Railways , 2020). The coastal cargo traffic at major and non-major ports has grown at a compound annual growth rate (CAGR) of 4 percent and 9.1 percent respectively between 2008–09 and 2021–22 (MoPSW, 2023). The coastal fleet has grown at a CAGR of 4 percent between 2008–09 and 2021–22 (MoPSW, 2023). This section maps out a vision for 2030 in terms of cargo handled, fuel consumed, energy, and emissions released for domestic shipping in the 'Baseline' scenario and the potential energy and emission savings in 'Transition to Green Shipping' scenario on adoption of alternative fuels like LNG and green ammonia.

7.1 Model Description

The key model variables are mentioned in Table 7.1.

Table 7.1: Model variables, definitions, and sources

Variables	Definition	Sources
Total coastal cargo traffic handled by both major and non-major ports	Cargo traffic handled is defined as the total of cargo unloaded, loaded, and transhipped. It is a scalar quantity with only magnitude and no direction.	Basic Ports Statistics of India, Ministry of Ports, Shipping and Waterways
Fuel consumption	This is the fuel consumed of each type i.e. diesel oil/gas oil, heavy fuel oil, and light fuel oil by selected Indian Flag Vessels operating on coastal run.	Annual Fuel Consumption Reports, Director General of Shipping (DGS), Ministry of Ports, Shipping and Waterways

Base year: The base year for this modelling exercise is 2021–22. Considering the notification regarding the need for getting fuel consumption, for large vessels (more than 5,000 GT), verified from International Maritime Organisation (IMO), the data with distinction between vessels on coastal and international operation are only available since 2019 (MoPSW, 2023).

Time-frame: The data on cargo handled is estimated for a period from 1995–96 to 2030–31. The data for fuel consumption spans for a period from 2019–20 to 2030–31.

Basic Considerations/Assumptions

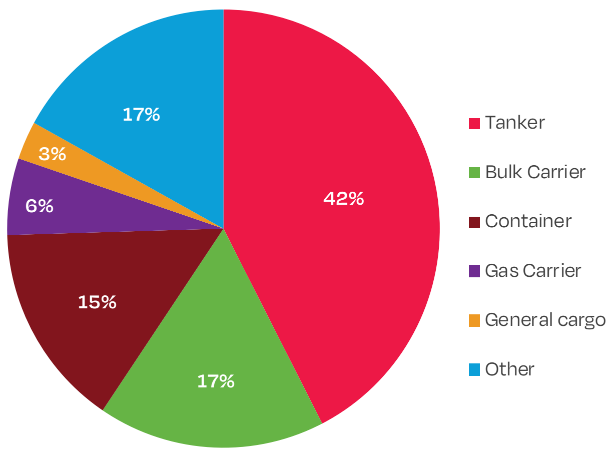
To estimate fuel demand, energy demand and GHG emissions, the fuel consumption for vessels particular to freight transport have been considered as shown in Table 7.2. Category 1 ships are used for both international and coastal operations. Approximately 45 percent of the total category 1 Indian Flag Vessels (relevant to cargo transport demand) are used in coastal operation (DGS). The share of each category of ships for the period 2022–23 to 2030–31 is assumed to be equal to the average of the shares for the period 2019–20, 2020–21, 2021–22 and is indicated in Table 7.2.

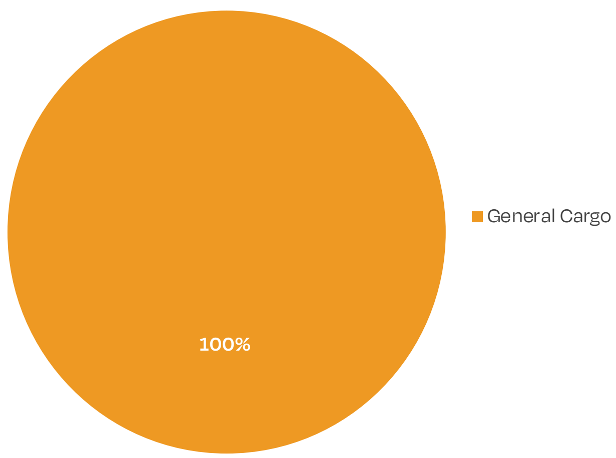
Table 7.2: Vessel types considered

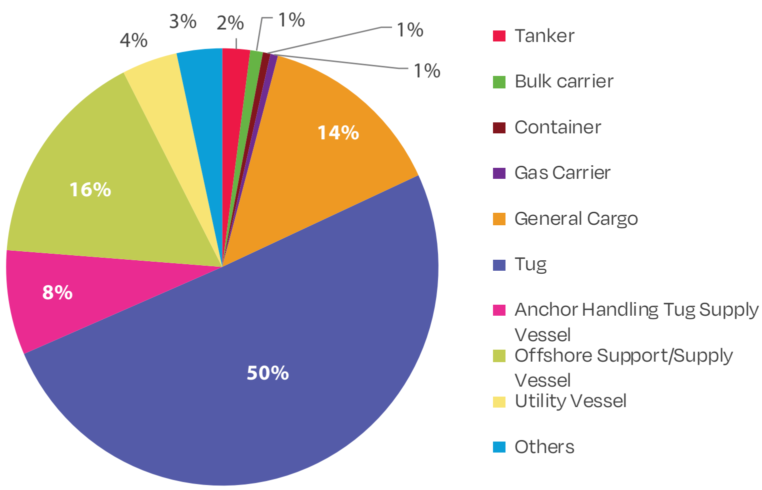
Ship Category	Description	Cargo Vessel Types Considered		Number of Indian Flag Vessels on Coastal Operation (2021-22)	Share of Each Category from 2022-23 to 2030-31 (%)
Category 1	≥ 5,000 GT	▪ Tanker ▪ Bulk Carrier ▪ Container	▪ Gas Carrier ▪ General Cargo ▪ Others	106	16
Category 2	≥ 5,000 GT (certified with RSV or ICV)	▪ General cargo		15	1
Category 3	< 5,000 GT	▪ Tanker ▪ Bulk Carrier ▪ Container ▪ Gas Carrier ▪ General Cargo ▪ Tug	▪ Anchor Handling Tug Supply Vessel ▪ Offshore Support/ Supply Vessel ▪ Utility Vessel ▪ Others	530	83
Total				**651**	

Note: The following vessel types have been omitted: passenger ship, high speed passenger crafts, dredgers, crew boats and launch vessels.
Source: Annual Fuel Consumption Report for Calendar Year 2021, Directorate General of Shipping, GoI.

Figure 7.1: Distribution of vessel types in ship categories of Indian flag vessels in coastal operation for 2021–22







Source: Annual Fuel Consumption Report for Calendar Year 2021, Directorate General of Shipping, GoI

Table 7.3 shows the CAGR assumed for diesel oil/gas oil, heavy fuel oil, and light fuel oil. The CAGR for diesel oil/gas oil is based on the historical trend observed for each category of ship. However, for light fuel oil, a weighted average growth rate was used where the weights were growth rates in total light fuel oil consumption in corresponding periods of limited data available. This was done because there was an uptake of light fuel oil in coastal shipping post 2020–21, due to the International Maritime Organisation (IMO)'s reduction in the upper limit of sulphur content in fuel oil from 3.5 percent to 0.5 percent since January 1, 2020.[61]

Table 7.3: CAGR for fuel consumed

Fuel Type	Category 1 Ship	Category 2 Ship	Category 3 Ship
Diesel Oil/Gas Oil	-5.7%	36.8%	0.5%
Heavy Fuel Oil	0.7%	29.7%	-18.5%
Light Fuel Oil	1.8%	0.0	20.4%

Source: TERI's calculations based on Annual Fuel Consumption Report for Calendar Year 2021, Directorate General of Shipping, GoI.

7.2 Methodology

Estimation of Coastal Cargo Traffic: Coastal cargo traffic has been estimated using Ordinary Least Squares (OLS) regression with growth of cargo traffic being regressed on GDP growth (at 2011–12 constant prices) and time.

Estimation of Fuel Use, Energy Demand and GHG Emissions: Fuel demand for each category of ships and each category of fuel has been estimated using CAGR approach based on historical trends for the available data. Using energy content and emission factors,[62] for each unit of fuel demanded, the corresponding energy demand and GHG emissions have been estimated.

The next section discusses the projected coastal cargo traffic based on the OLS estimates obtained.

7.3 Coastal Cargo Traffic Projection

Figure 7.2 shows the projected coastal cargo traffic (till 2030–31) *versus* the actual coastal cargo traffic. GDP growth was found to have a significant impact on the growth in coastal cargo traffic. The coastal cargo traffic is estimated to increase 1.7 times in 2030–31 as compared to 2021-22 (from 264 MMT in 2021–22 to 467 MMT in 2030–31).

[61] Details available at https://www.imo.org/en/MediaCentre/PressBriefings/pages/02-IMO-2020.aspx
[62] For estimating energy demand and GHG emissions, well to wake energy and emissions factors have been considered.

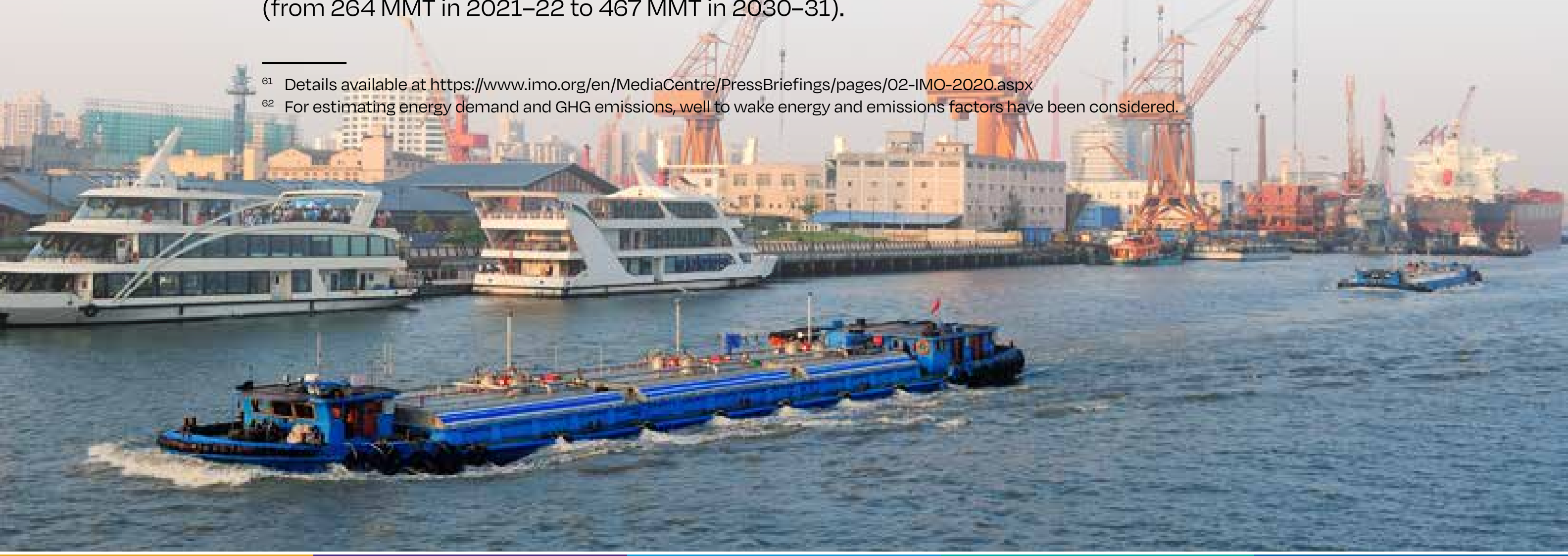
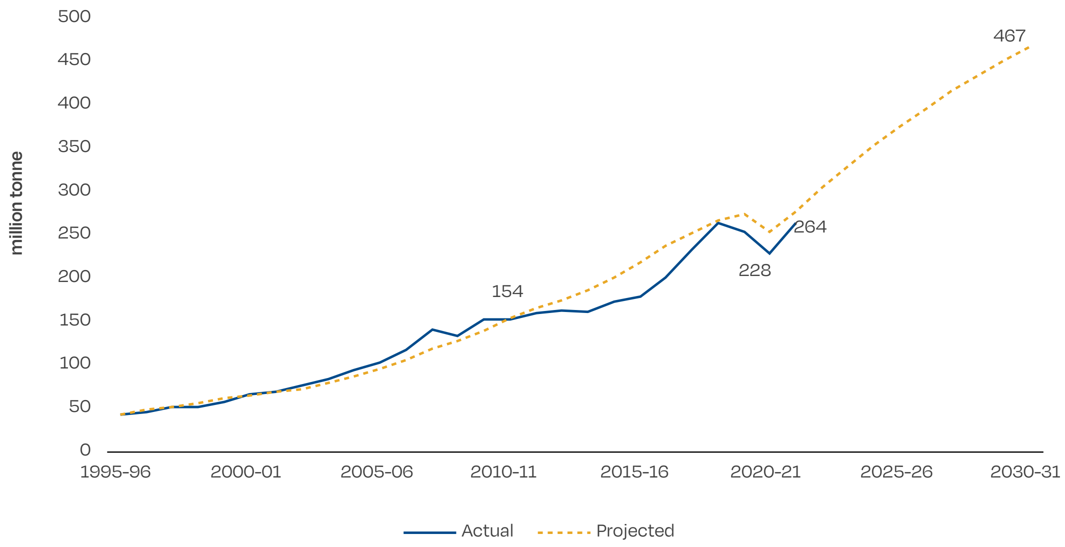


Figure 7.2: Actual vs. projected coastal cargo traffic

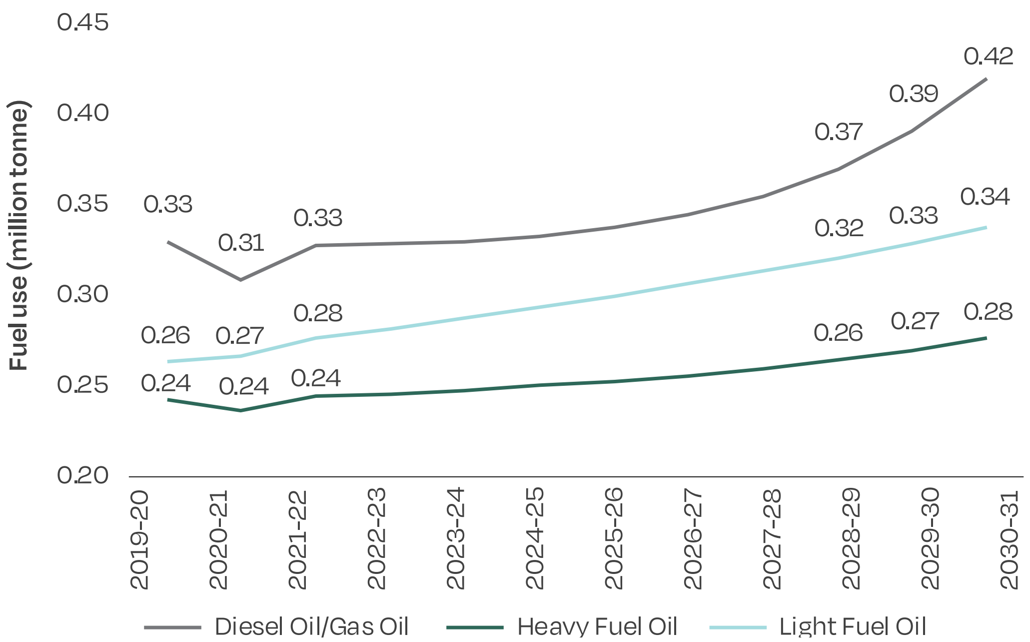


Source: TERI

7.4 Fuel Use, Energy Demand and GHG Emissions: Baseline Scenario

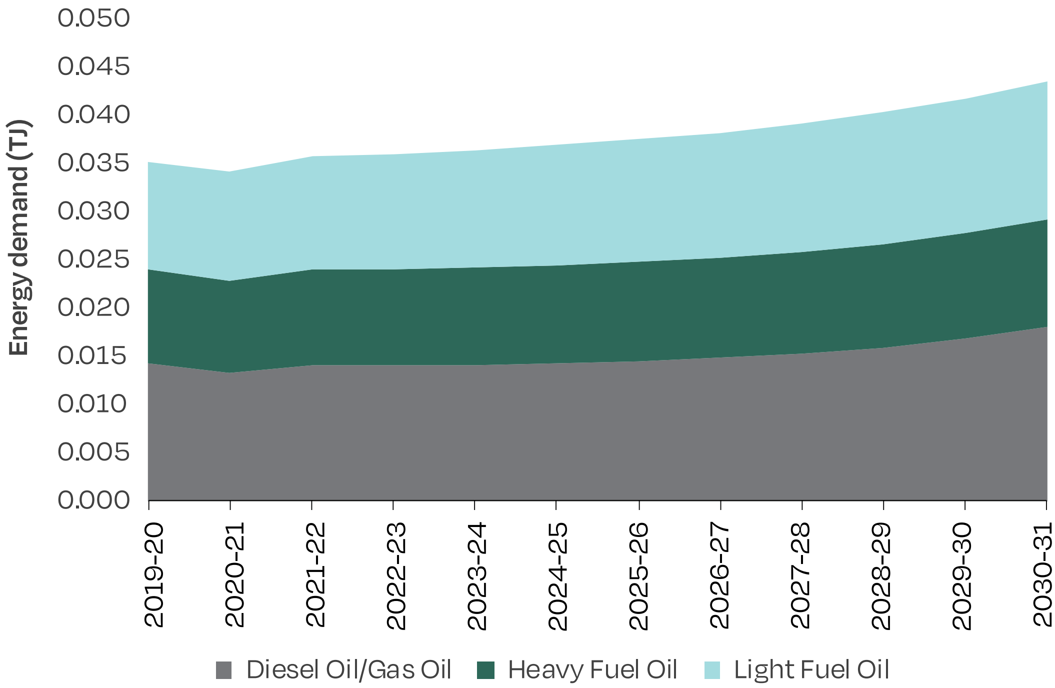
Figure 7.3, Figure 7.4, and Figure 7.5 present the fuel use (measured in million tonne), energy demand (measured in tera-Joules, TJ) and GHG emissions (measured in million-tonne CO_2e) from Indian flag vessels on coastal operation under the baseline scenario.

Figure 7.3: Fuel use by Indian flag vessels on coastal operation in baseline scenario



Source: TERI

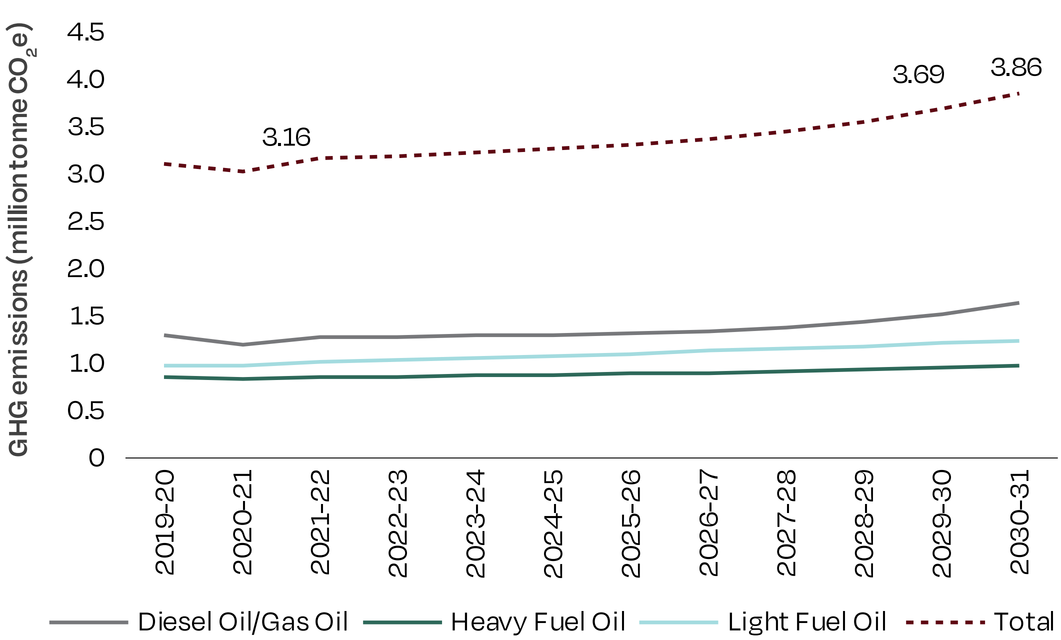
Figure 7.4: Energy demand by Indian flag vessels on coastal operation in baseline scenario



Source: TERI

Demand for light fuel oil is expected to pick up and a grow at a CAGR of 2.3 percent followed by diesel oil at 2.2 percent and then heavy fuel oil at 1.2 percent between 2019–20 to 2030–31. The total energy demand is expected to increase by 25 percent between 2019–20 and 2030–31 (from 0.035 TJ in 2019–20 to 0.044 TJ in 2030–31).

Figure 7.5: GHG emissions by Indian flag vessels on coastal operation in baseline scenario



Source: TERI

GHG emissions from Indian flag vessels in coastal operation are expected to increase by 24 percent between 2019–20 and 2030–31 (from 3.11 million tonnes of CO_2e in 2019–20 to 3.86 million tonnes of CO_2e in 2030–31). Diesel oil is expected to contribute the highest share in GHG emissions (43 percent) followed by light fuel oil (32 percent) and then heavy fuel oil (25 percent) in 2030–31.

7.5 Foundations of 'Transition to Green Shipping' Scenario

As mentioned in IMO's fourth GHG study, two categories of alternative fuel adoption have been mentioned – Group 15A and Group 15B (IMO, 2021). This is elaborated in Table 7.4. Other factors like adoption of renewable energy on ports and efficiency improvement of ships have been kept as *status quo*.

The rationale for taking the specified shares in LNG is based on the present consumption share of LNG in international shipping in Category 1 ships of Indian flag vessels and a similar adoption pattern has been carried out starting from 2029–30. The rationale for choosing ammonia in Category 1 and Category 3 ships is drawn from the in-country targets under the National Green Hydrogen Mission and the Green tug transition program. The reduction in other shares of fuel technologies based on adoption of LNG and ammonia has been done considering the trend observed in global emission reduction by different vessel categories like tankers, bulk carriers, containers, etc. as observed in the Fourth IMO GHG study of 2020 (IMO, 2021). The exploration of switch to complete non-fossil fuel-based technologies for domestic shipping has been left for future research with a broad time horizon due to data limitations for coastal shipping in India.

The National Green Hydrogen Mission requires the Shipping Corporation of India to retrofit at least 2 ships to be powered by green hydrogen and its derivatives by 2027 and India's oil and gas Public Sector Undertakings to charter at least one ship powered by green hydrogen and its derivatives by 2027 followed by annual addition of at least one ship thereafter (MNRE, 2023). The Ministry of Ports, Shipping and Waterways has declared the responsibility of introducing at least 2 ships powered by green hydrogen and/or its derivatives by 2027 followed by annual addition of 2 ships thereafter in its Marine Environmental Management Report of 2023 (MoPSW, 2023). Distributing ammonia powered ships based on coastal and international operations, gives the penetration shares of ammonia in category 1 ships as shown in Table 7.4.

Secondly, tugs constitute 32 percent of all Indian vessels (MoPSW, 2023) and fall under category 3 ships. Hence, Green Tug Transition program aims to convert 50 percent of all tugs to be powered by 'Green Hybrid Propulsion Systems' followed by complete switch to non-fossil fuel-based technologies by 2030 (MoPSW, 2023). To show that transition, 25 percent of all tugs have been assumed to be powered by ammonia by 2029–30 and 50 percent is then achieved by 2030–31. The distinction between hybrid and pure use of any technology has not been undertaken in this modelling exercise.

Table 7.4: Assumptions in 'transition to green shipping' scenario

Use of Alternative Fuels	IMO Group Category	Technology	Applied to Ship Category	Penetration of Technology[a]		
				2028-29	2029-30	2030-31
LNG	15A: Use of alternative fuel with carbon	LNG + ICE or FC	Category 1 only	-	0.02%	0.03%
Ammonia	15B: Use of alternative fuel without carbon	Ammonia + ICE or FC	Category 1/ Category 3	0.51%/ 0%	0.99%/ 3.43%	1.42%/ 6.56%

Note: [a] Penetration of technology

$$= \frac{\text{X or Y alternative fuel consumed in Category 1 or 2 or 3 ship}}{\text{Total fuel (all types) consumed (in Category 1,2,and 3 ships)}}$$

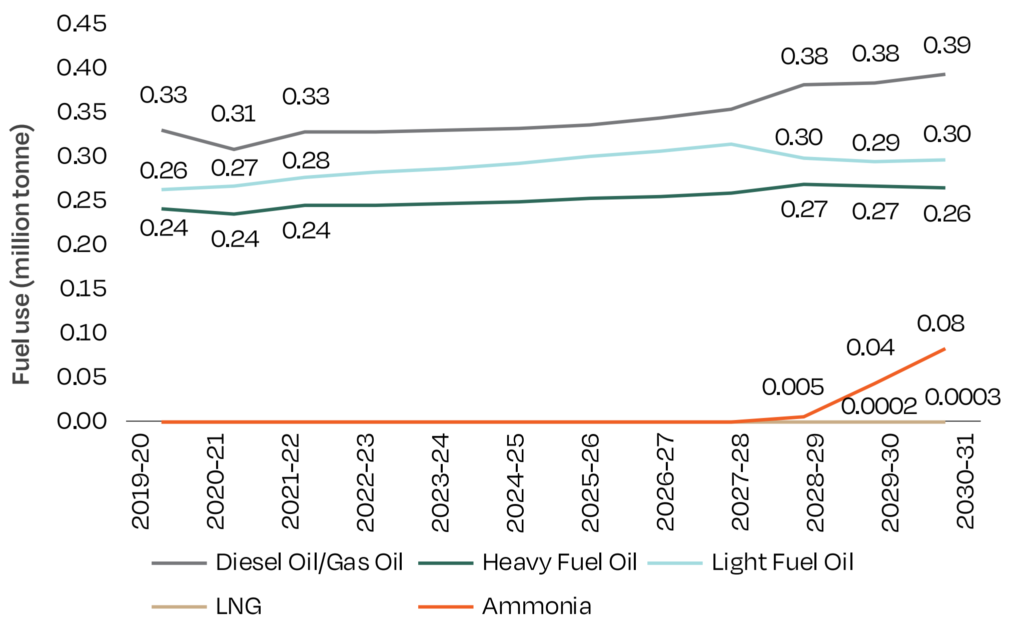
The numerator is calculated based on percentage share of vessels operating with the new technology out of the total vessels operating.

Use of biofuels have not been accounted here as the global share of ethanol, used cooking oil, liquified biogas (LBG), etc. is only 0.05 percent (in ships greater or equal to 5,000 GT) which in case of Indian flag vessels (both coastal and international operation) would only account for a meagre 0.00018 percent (IMO, 2021). However, it should be noted that the Ministry of Ports, Shipping and Waterways has released a notice regarding the guidelines on use of biofuels and blending for Indian ships in November 2023 and the same could be explored upon further developments on supply and demand fronts (MoPSW, 2023).

7.6 Results: 'Transition to Green Shipping' Scenario

Figure 7.6, Figure 7.7, and Figure 7.8 present the fuel use (measured in MMT), energy demand (measured in TJ) and GHG emissions (measured in million tonnes of CO_2e) from Indian flag vessels on coastal operation under the 'Transition to Green Shipping' scenario.

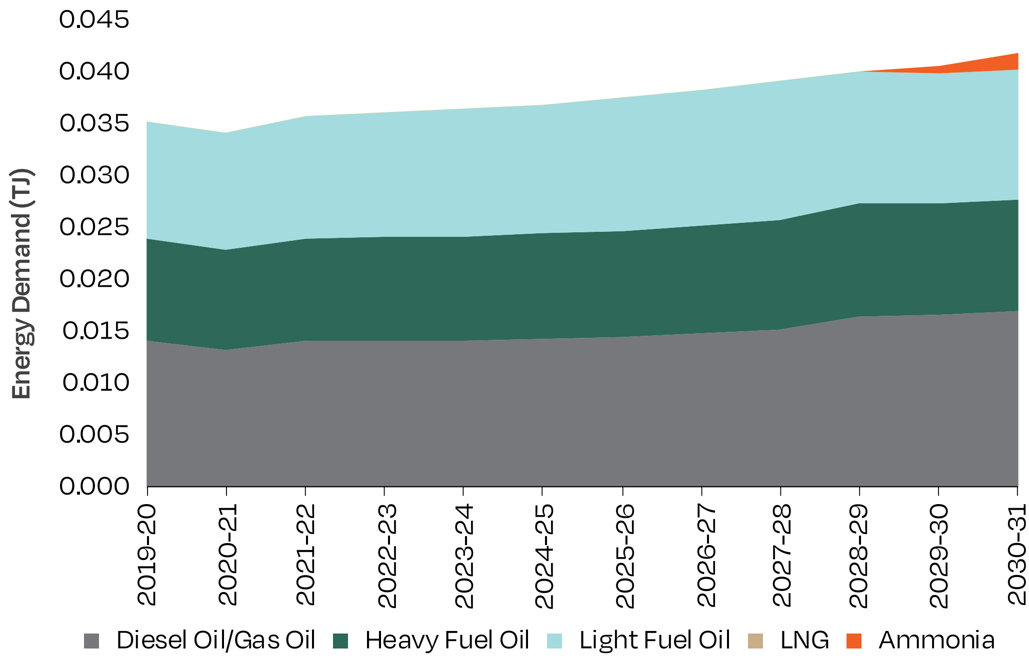
Figure 7.6: Fuel use by Indian flag vessels on coastal operation in 'transition to green shipping' scenario



Source: TERI

The introduction of ammonia in Category 1 ships has displaced the consumption of light fuel oil which decreased from 0.32 MMT in the baseline scenario to 0.3 MMT in the 'Transition to Green Shipping' scenario in 2028–29. In 2029–30, with greater adoption of ammonia and introduction of LNG, the consumption of diesel oil has decreased from 0.39 MMT in the baseline scenario to 0.38 MMT in 'Transition to Green Shipping' scenario. Heavy fuel oil is expected to remain constant (0.27 MMT) with light fuel oil's consumption decreasing to 0.29 MMT in the 'Transition to Green Shipping' scenario from a corresponding consumption of 0.33 MMT in the baseline scenario. In 2030-31, diesel oil drops by 7.1 percent (0.42 to 0.39 MMT), heavy fuel oil falls by 7.1 percent (0.28 to 0.26 MMT), and light fuel oil drops by 13.3 percent (0.34 to 0.3 MMT) in 'Transition to Green Shipping' scenario as compared to baseline scenario.

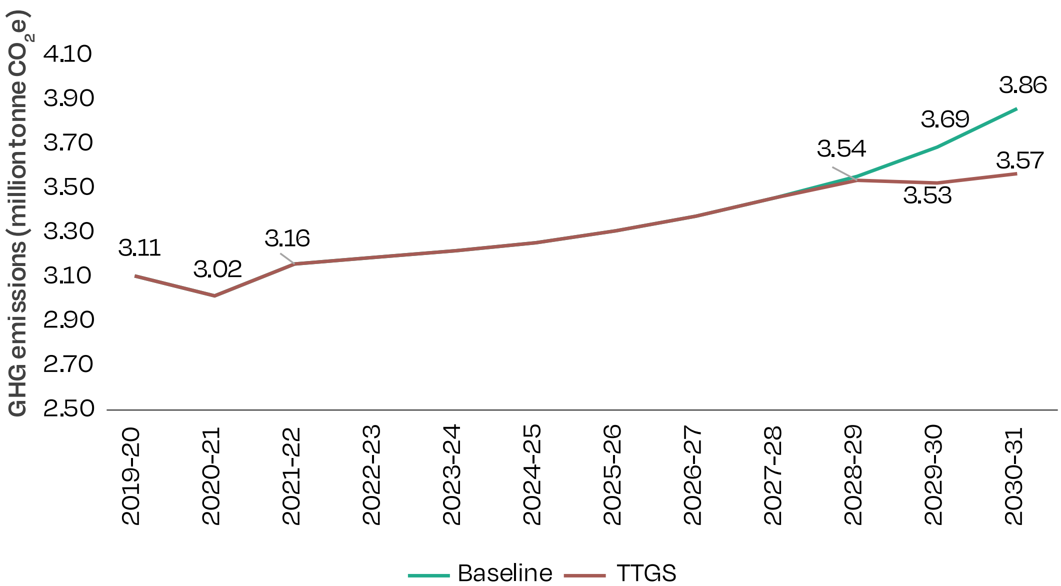
Figure 7.7: Energy demand by Indian flag vessels on coastal operation in 'transition to green shipping scenario'



Source: TERI

Energy demand is the same in both scenarios for the year 2028–29. However, in 2029–30 and 2030–31, the energy demand has decreased from 0.042 TJ and 0.044 TJ in baseline scenario to 0.04 TJ and 0.04 TJ in 'Transition to Green Shipping' scenario respectively. This fall has come about through decrease in energy demand in diesel oil and light fuel oil.

Figure 7.8: GHG emissions by Indian flag vessels on coastal operation in 'transition to green shipping (TTGS)' scenario



Source: TERI

GHG emissions have decreased from 3.56, 3.69, and 3.86 million tonnes of CO_2e from baseline scenario to 3.54, 3.53, and 3.57 million tonnes of CO_2e in 'Transition to Green Shipping' scenario in 2028–29, 2029–30, and 2030–31 respectively. LNG would be responsible for 0.00089 million tonnes of CO_2e and 0.0015 million tonnes of CO_2e in 2029-30 and 2030–31 respectively. Ammonia would be responsible for 0.00024, 0.0021, and 0.004 million tonnes of CO_2e in 2028-29, 2029-30, and 2030-31 respectively.

Adoption of alternative fuels as specified in the 'Transition to Green Shipping' scenario in Indian flag vessels in coastal operations is estimated to result in energy savings of 9.1 percent and emissions savings of 7.5 percent as compared to the baseline scenario in 2030-31 as shown in Table 7.5.

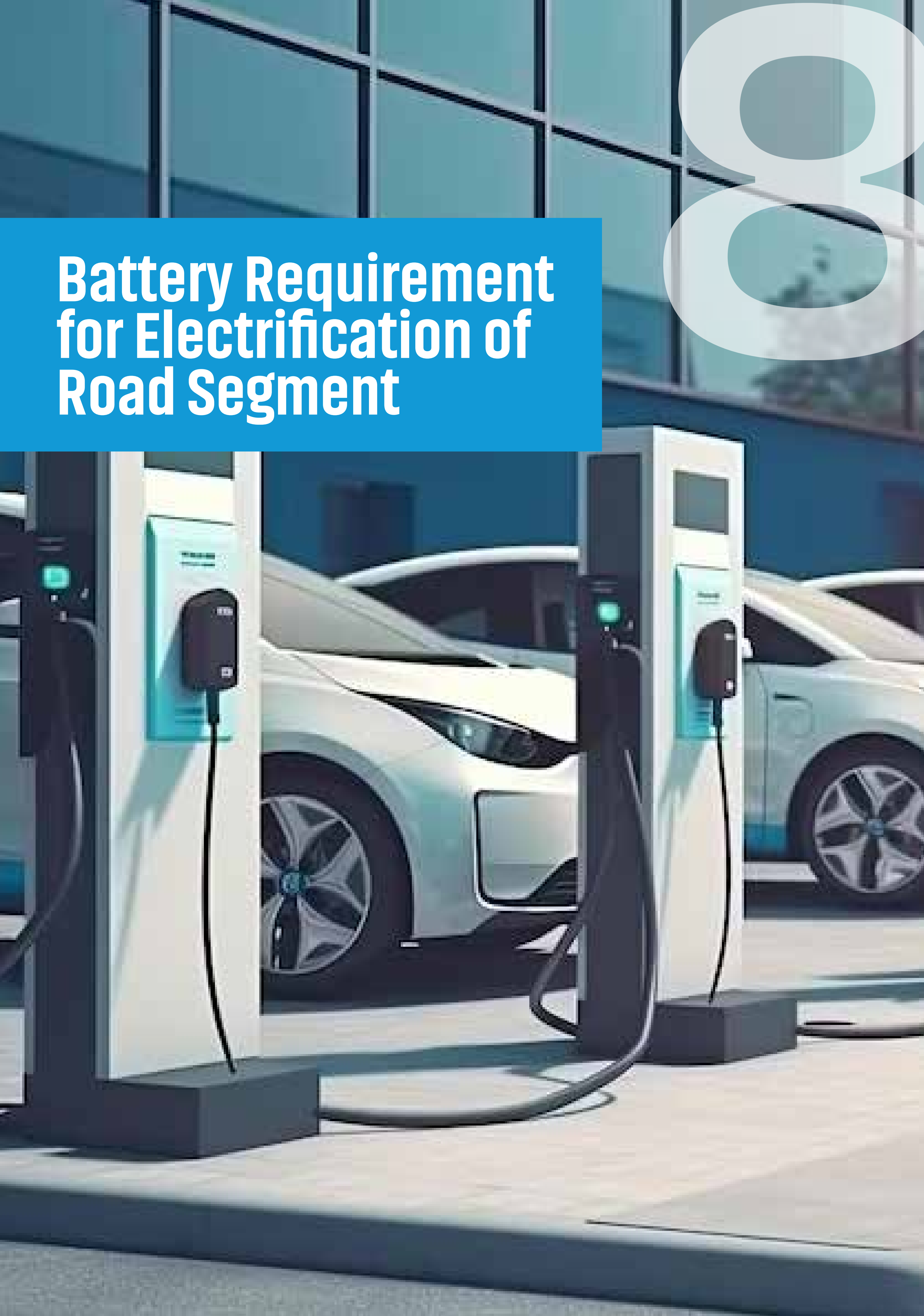
Table 7.5: Energy and emission savings in 'transition to green shipping' scenario

	2021-22	2028-29			2029-30			2030-31		
	Baseline/ Transition to Green Shipping	Baseline	Transition to Green Shipping	% Drop	Baseline	Transition to Green Shipping	% Drop	Baseline	Transition to Green Shipping	% Drop
Energy Demand (TJ)	0.036	0.040	0.040	0	0.042	0.040	4.7	0.044	0.040	9.1
GHG Emission (mtCO_2e)	3.16	3.56	3.54	0.6	3.69	3.53	4.3	3.86	3.57	7.5

Source: TERI

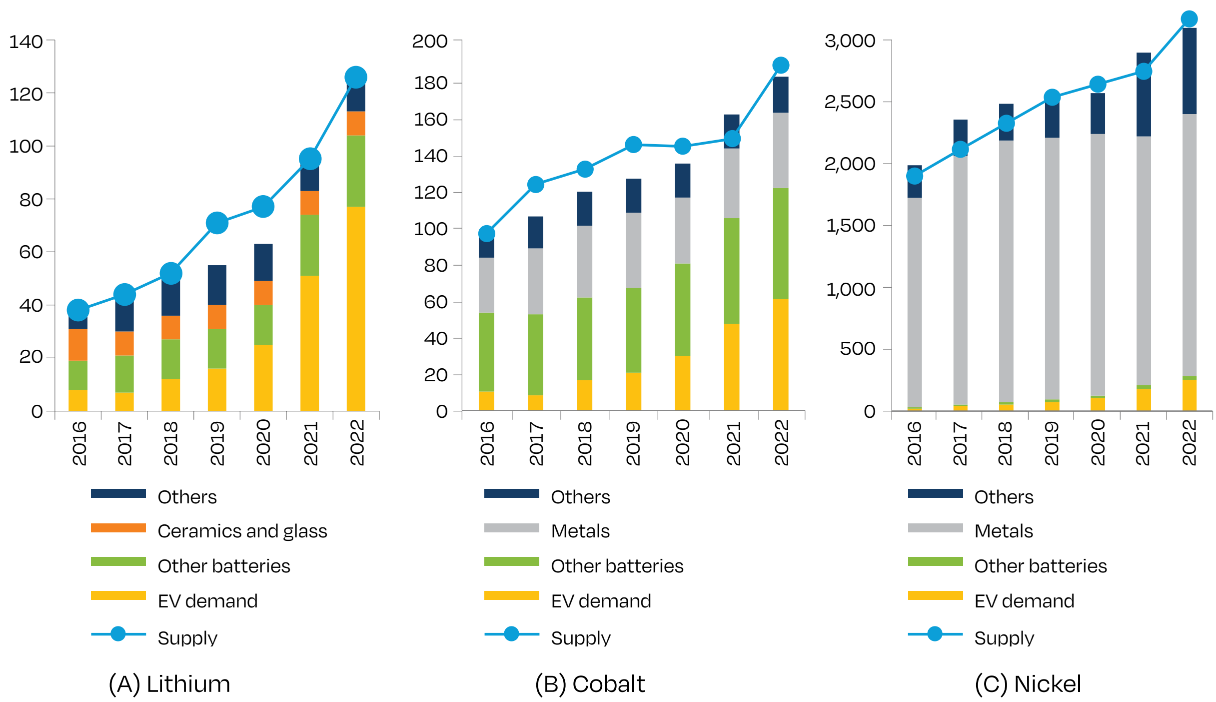
8

Battery Requirement for Electrification of Road Segment



Encouraged by the increasing outlook for electric vehicles (EVs) especially in the passenger segment, battery manufacturing for EVs will continuously expand. Globally, the demand for automotive lithium-ion (Li-ion) batteries increased by about 65 percent from about 330 GWh in 2021 to 550 GWh in 2022, as a result of 55 percent increase in new vehicle registrations during the same timeframe (IEA, 2023). Currently, most battery electric vehicle (BEV) and plug-in hybrid electric vehicles (PHEVs) use Li-ion batteries; though, the exact chemistry varies depending on vehicle type.[63] The increase in battery demand implied by EV deployment will drive the demand for critical minerals. Subsequently, there will be a significant increase in lithium demand, particularly in scenarios consistent with GHG reduction targets (Speirs et al., 2014). Figure 8.1 indicates the overall supply and demand of lithium, cobalt, and nickel for batteries by sector. In 2022, 60 percent of lithium, 33 percent of cobalt, and 8 percent of nickel demand was for EV batteries compared to around 21 percent, 10 percent, and 1 percent, respectively in 2016 (IEA, 2023). The lithium demand exceeded supply in 2022 despite 230 percent increase in production since 2016.

Figure 8.1: Overall supply and demand of (A) lithium, (B) cobalt, and (C) nickel for batteries by sector (in kilo-tonnes)



Source: Trends in batteries – Global EV Outlook 2023 – Analysis - IEA

In India, BEV sales reached above 1.5 million in 2023, 8 times more than in 2019.[64] India's commitment towards EVs in the baseline scenario translates to about electric 8.6 million 2Ws, 0.5 million 3Ws, 0.9 million 4Ws, 0.3 million LGVs, 15 thousand buses, and 34 thousand MHGVs (assuming all EVs to be BEVs) by 2030.[65] However, in India battery cell manufacturing industry is in the nascent stage and is heavily reliant on imports to meet its EV component needs (Gode et al., 2021). The eligibility criteria for FAME-II included domestic manufacturing of parts for 2Ws, 3Ws, passenger cars, and buses; however, there were no restriction on sourcing battery cells or battery management system and manufacturers only assembled battery packs in India.

[63] https://afdc.energy.gov/vehicles/electric_batteries.html
[64] https://vahan.parivahan.gov.in/vahan4dashboard/
[65] TERI

8.1 Battery Chemistries

The EV technology has evolved significantly over the past decade with the batteries as the critical component. Lead-acid batteries are made up of lead dioxide (PbO_2) for positive electrode, lead for negative electrode, and sulphuric acid solution as a separator (Energy5, 2024). These have several disadvantages such as low specific energy which in turn causes the battery to be heavy, shorter lifespan compared to other battery types, requirement of regular maintenance, and severe environmental impact of lead.[64] The advanced type of batteries have considerably increased efficiency and have lesser contamination impact.

Lithium is the lightest metal and has an extremely negative electrode potential and Li-ion batteries have higher energy density than lead-acid batteries and operate at room temperature (Speirs et al., 2014). These favourable characteristics, high power density, and long cycle life has made Li-ion batteries the current technology choice for EVs. Lithium-ion refers to an array of battery chemistries; however, in general there is a lithium oxide cathode and a graphite anode. Commonly used lithium-ion chemistries are lithium nickel manganese cobalt (NMC) and lithium iron phosphate (LFP) with 60 and 30 percent market share respectively in 2022 (IEA, 2023). There are other lithium-ion batteries such as lithium nickel cobalt aluminium oxide (NCA), and lithium manganese oxide (LMO) at the cathode (PNNL, n.d.). Among these battery chemistries, critical minerals are cobalt, lithium, nickel, and graphite.

NMC811 is a high nickel battery chemistry, which consists of 80 percent nickel, 10 percent manganese, and 10 percent cobalt in the cathode. NMC622, another high nickel battery, comprises of 60 percent nickel, 20 percent manganese, and 20 percent cobalt. NMC523 batteries cathode composition consists of 50 percent nickel, 20 percent manganese, and 30 percent cobalt.[66] NMC811 chemistry uses a much lower amount of cobalt than the older NMC111 technologies (Gifford, 2022). High nickel content offers more energy, but reduced cycle times, and requirement of dry rooms during manufacturing increases costs. However, overall low cost and high capacity of nickel relative to cobalt makes it an attractive prospect for EV batteries.

There has been a substantial increase in market share of LFP batteries from 6 percent in 2020 to 30 percent in 2022 (EV Markets Reports, 2023). The LFP cathode has lithium carbonate, and the composition consists of 61 percent phosphate, 35 percent iron, and 4 percent lithium (Grandi, 2023). LFP batteries have low risk of overheating therefore less prone to thermal runaway, low degradation rate, and can withstand higher number of charge and discharge cycles, and iron and phosphate, main cathode materials, are in relative abundance which reduces overall cost by 30–40 percent (Clemens, 2023) compared to NMC. However, it has lower energy density which implies lower EV range on a charge for same weight as an NMC battery.

Solid-state chemistries, such as lithium-lithium metal oxide (Li-LMO), lithium-sulphur (Li-S), and lithium-air (Li-air), which have high lithium than other chemistries, are in development stages. In a solid-state battery, the electrolyte is solid which allows ions to move faster and has greater tolerance of high voltages and temperatures[67] especially in extreme conditions. Faster movement of ions enable shorter charging times and increased cruising ranges produce higher power output. However, repeated battery charging and discharging causes cracks between cathodes, anodes, and solid electrolytes which degrades the battery performance (Winkless, 2023).

With ongoing research and development, new technologies for EV batteries are expected emerge to optimise overall cost, extend useful battery life, reduce use of toxic metals, and address safety concerns.

[66] Details available at The key minerals in an EV battery - MINING.COM

[67] https://media.toyota.co.uk/toyota-sets-out-advanced-battery-technology-roadmap/

8.2 EV Battery Requirement

This section discusses in detail about the forecast of EV battery demand for the Indian road transport sector. Under the four scenarios– baseline, policy-in-action (PIA), Ambitious, and Highly Ambitious, (i) number of batteries, (ii) energy requirements, (iii) cost of batteries, and (iv) critical mineral requirement were estimated. Given the high BEV penetration and negligible numbers of PHEVs in India, it was assumed that moving forward all EV categories would be fully battery electric hence PHEVs excluded from the analysis. Using TERI-TptM, the number of BEVs, in millions, has been estimated for the four scenarios.

Further, given that currently NMC chemistry dominates the EV battery market and further expected to penetrate by 2030 (Gifford, 2022); therefore, corresponding number of NMC811 batteries required for these EV scenarios was estimated. A factor of 1.5 was assumed, taking into consideration the requirement of battery swapping (Table 8.1).

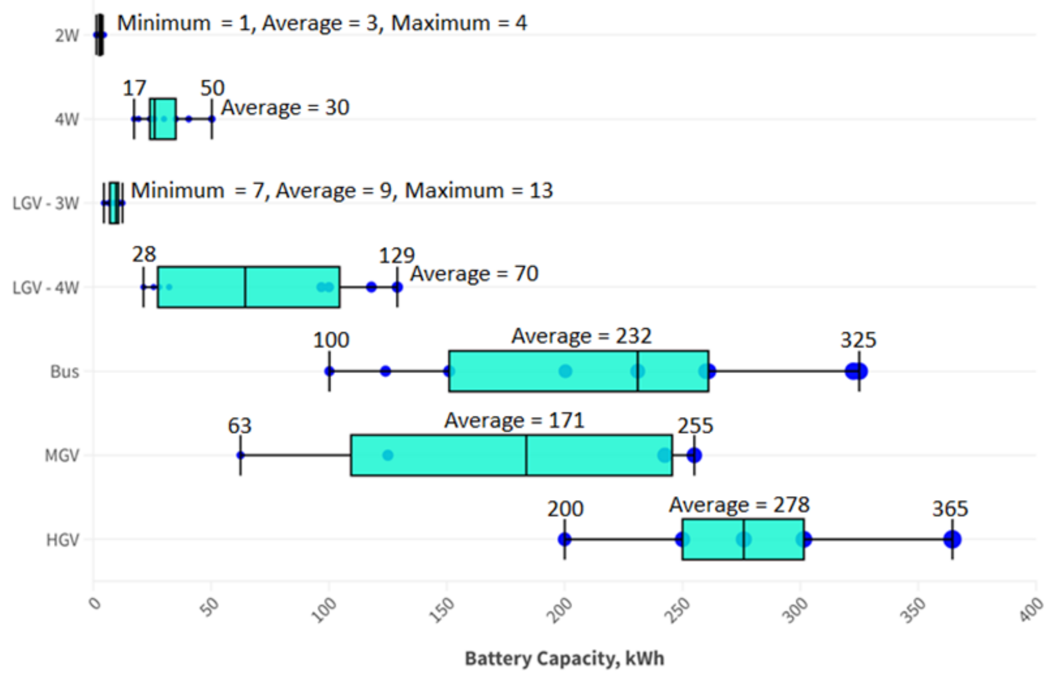
Table 8.1: Number of EV batteries in different scenarios (millions)

	2W	3W	4W	Bus	LGV	MHGV
Baseline						
2030–31	12.9	0.6	1.4	0.02	0.4	0.05
2040–41	36.2	2.4	7.2	0.05	1.4	0.2
2050–51	68.8	6.0	27.4	0.08	3.2	0.7
2070–71	202.7	17.4	99.8	0.2	8.0	2.0
Policy-in-Action						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2040–41	229.1	8.7	42.7	0.5	2.9	2.1
2050–51	335.9	16.4	114.3	1.0	5.6	5.5
2070–71	570.6	52.8	257.2	1.8	12.7	13.2
Ambitious						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2040–41	249.5	9.2	55.5	0.6	3.3	2.9
2050–51	353.9	24.9	148.8	1.3	8.1	8.1
2070–71	760.3	52.8	307.3	2.0	19.4	19.8
Highly Ambitious						
2030–31	77.2	2.7	6.6	0.2	0.6	0.3
2040–41	263.1	9.8	62.1	0.8	4.1	3.2
2050–51	450.4	27.5	164.9	1.5	10.8	9.7
2070–71	760.3	52.8	407.6	3.0	32.8	30.6

Note: 4W includes 4W-C&J and 4W-T, LGV includes 3W and 4W goods vehicles.
Source: TERI

The corresponding total energy demand (in terawatt-hour, TWh) for number of batteries was estimated based on average battery size of each vehicle segment as given in Figure 8.2. The average battery capacity was considered based on the current vehicle models in the market of 2W, 4W, LGV, and bus segments. For LGVs, both 3Ws and 4Ws were considered and the average was 42 kWh; given 45 percent share of 3Ws and 55 percent share of 4Ws in LGV segment; for 3W-P segment, it was considered to be 5 kWh based on FAME-II policy. For MGHVs, the average battery capacity considered was 225 kWh based on few models in the Indian and international (in same GVW segment) market.

Figure 8.2: Average battery capacity in different vehicle segments

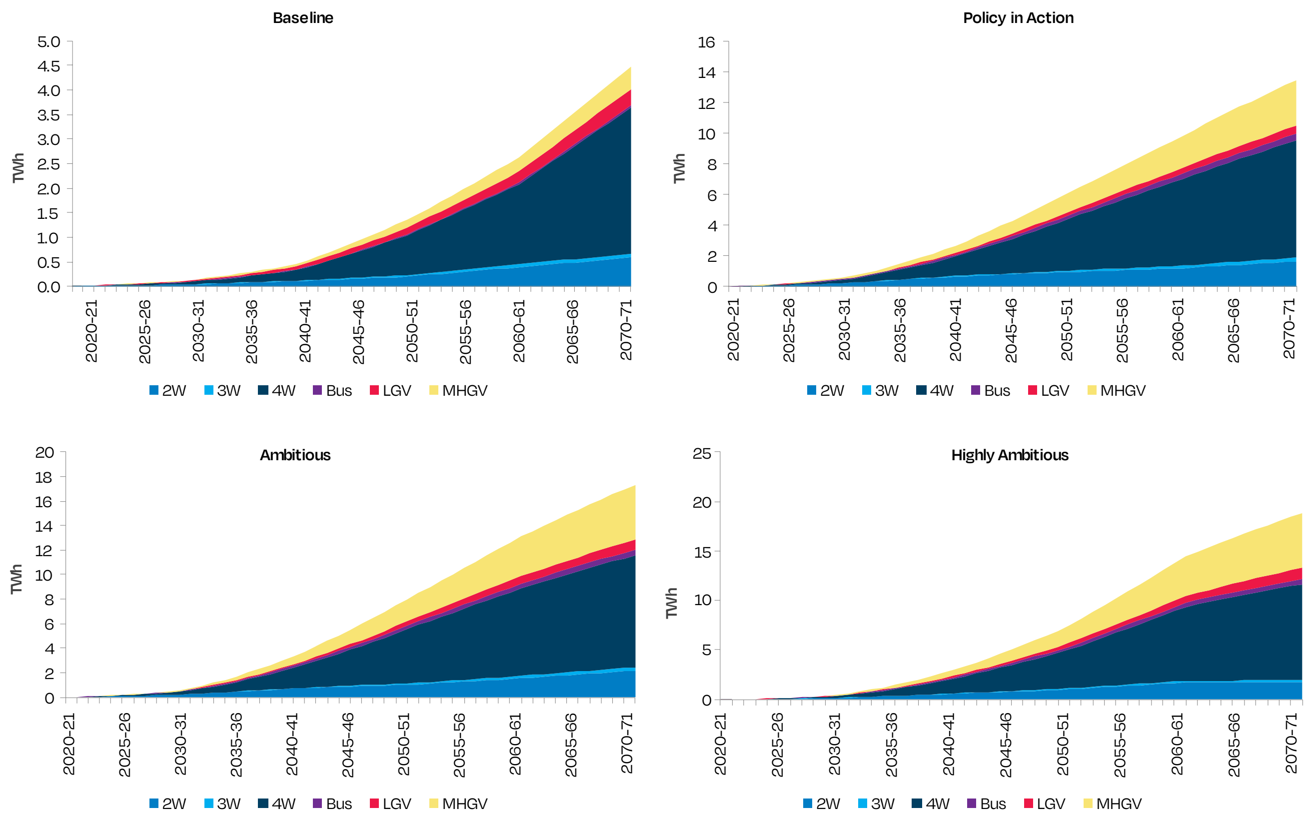


Source: TERI Compilation

Based on the average battery size and number of EV batteries, the energy demand for each segment was estimated, as given in Figure 8.3. The energy requirement for PIA, Ambitious, and Highly Ambitious scenarios was found to be five times i.e., 0.57 TWh in 2030–31 compared to the baseline scenario.

In 2030–31, given the uptake of passenger segment— 2W and 4W, the total battery demand is expected to be mainly constituted of the two segments in all scenarios. However, due to projected uptake of electric MHGVs in the PIA, Ambitious, and Highly Ambitious scenarios and a higher average battery size, the energy requirement along with 4Ws would be more 75 percent of total energy requirement.

Figure 8.3: Vehicle segment-wise energy requirement of EV batteries



Source: TERI

8.2.1 Battery Cost

With limited domestic production of Li-ion cells, battery constitutes 39 percent of the manufacturing cost of electric passenger 4Ws (Maitr et al., 2022). Currently, Li-ion cells are imported, and further manufacturing/assembly of battery pack is done domestically. Globally, prices of Li-ion cells and battery pack are expected to reduce in future. The battery pack prices have fallen from USD 1,100 per kWh in 2010 (BloombergNEF, 2020) to USD 139 per kWh in 2023 (BloombergNEF, 2023).

The associated battery cost with the energy requirement can be described by equation 1.

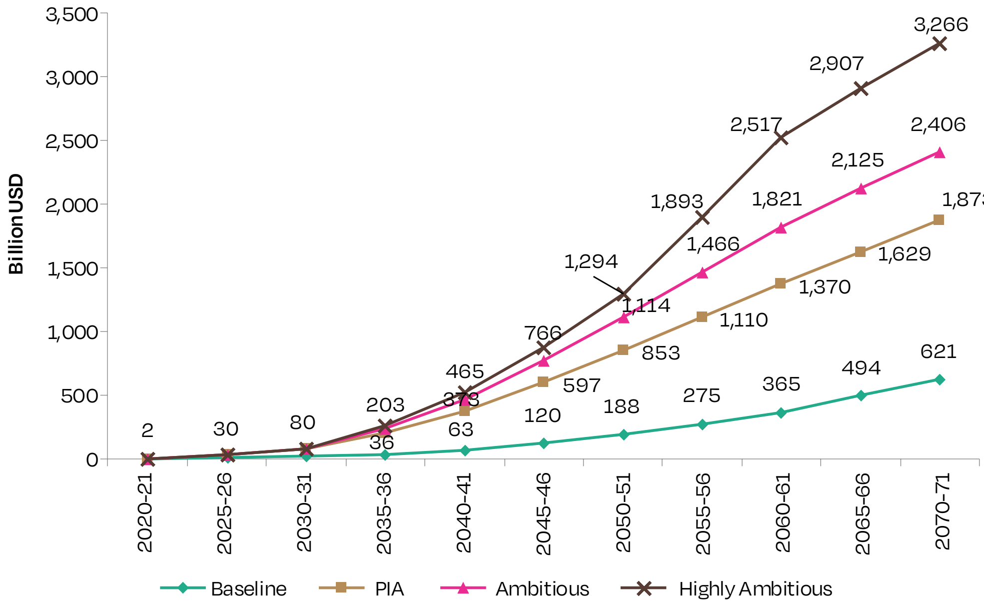
$$C_m = (EV_m x1.5)xS_m x139 \qquad (1)$$

Where,

C_m = Battery cost of vehicle segment m in USD, EV_m = Number of electric vehicles in that segment m, S_m = Average battery size of EV segment m in kWh.

Figure 8.4 presents the cost of battery requirement in the three scenarios. The battery cost in PIA scenario is estimated to reach 4.5 and 3.0, in the Ambitious scenario 5.5 and 3.9 times, and in the Highly Ambitious scenario 6.8 and 5.2 times than the baseline scenario by 2050–51 and 2070-71.

Figure 8.4: Cost of battery in different scenarios



Source: TERI

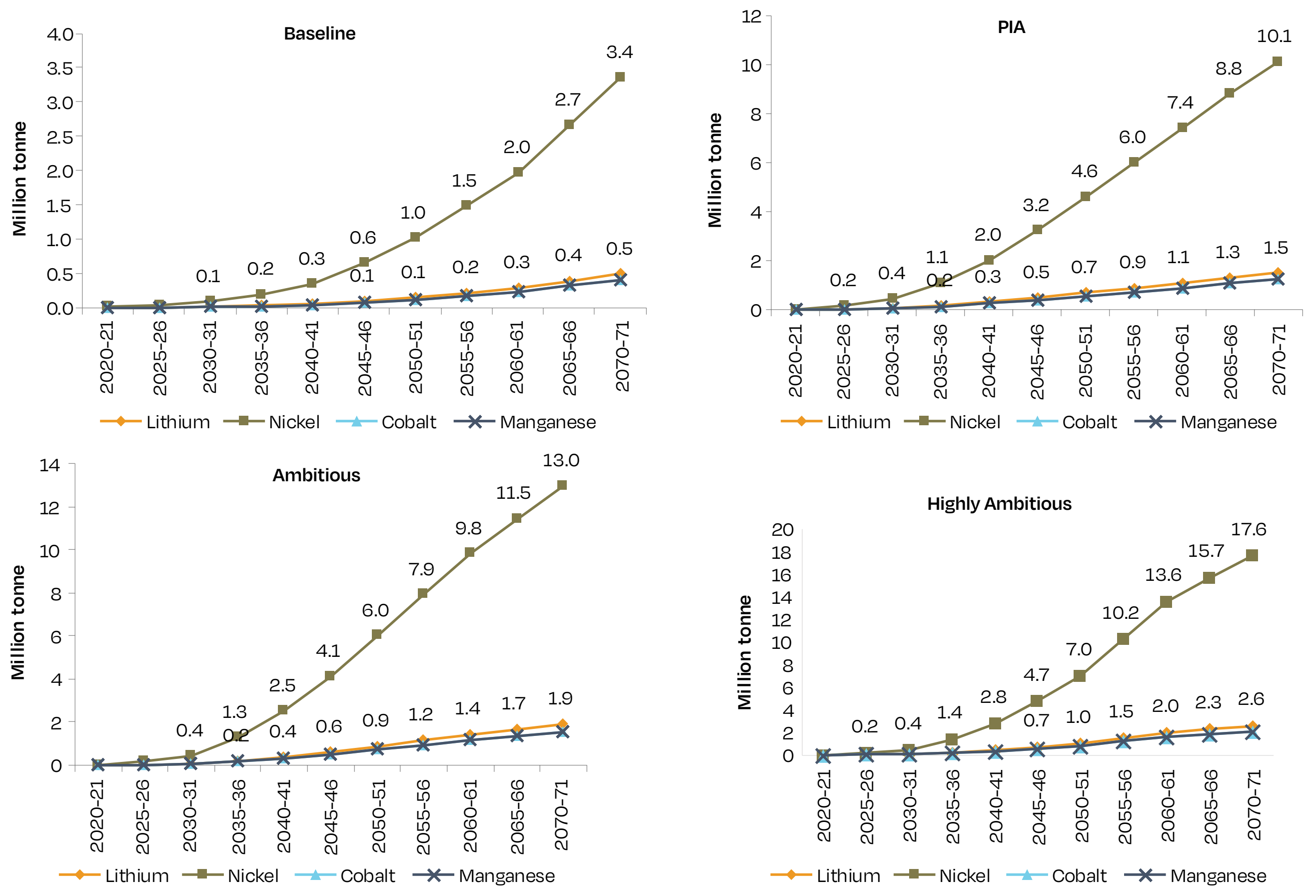
8.2.2 Critical Mineral Requirements for Electric Vehicle Batteries

An EV transition of high magnitude would require manufacturing large quantities of Li-ion batteries and consequently substantial amounts of raw materials such as lithium, nickel, cobalt, and manganese. Currently, India imports almost 70 percent of its Li-ion cell requirement (Maitr et al., 2022). The critical minerals of an NMC811 batteries i.e., lithium, nickel, manganese, and cobalt were estimated in each scenario shown in Figure 8.5. These batteries would require 0.6 and 1.5 million tonnes in 2050-51, and 2070-71 of lithium in PIA scenario respectively. In the Ambitious scenario, there would be a requirement of 0.8 and 1.9 million tonnes in 2050-51 and 2070-71 of lithium respectively. In the Highly Ambitious scenario, the lithium requirement would be 1.0 and 2.6 million tonnes in 2050-51 and 2070-71 respectively. In the global scenario, the estimated reserves were 28 million tonnes[68] and the total mine production of lithium was 0.13 million tonnes[69] in 2022. It is estimated that critical minerals required to meet EV battery demand, mainly for lithium and cobalt, will surpass the known reserves by 2050 if low rates of recycling were maintained (IEA, 2023). Therefore, these estimated amounts of critical minerals required to meet EV battery demand, mainly for lithium and nickel, would have to be met through recycling of EV batteries.

[68] https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-lithium.pdf

[69] https://natural-resources.canada.ca/our-natural-resources/minerals-mining/mining-data-statistics-and-analysis/minerals-metals-facts/lithium-facts/24009

Figure 8.5: Critical minerals requirement in different scenarios



Source: TERI

8.3 Other Technologies

Current research in lithium batteries focuses on increased safety, lower costs, increased energy density, and improved cycle life (Speirs et al., 2014). Li-ion battery requirements often conflict in energy density, crucial for longer vehicle ranges, and high-power density, essential for fast-charging capabilities (EV Markets Reports, 2024). Two alternative lithium-based chemistries currently being developed are lithium–air and lithium–sulphur. Both technologies have higher energy density and thus ability to improve the driving range of EVs compared to current Li-ion batteries (Speirs et al., 2014). Metal air chemistries such as sodium air and zinc air are also alternatives to lithium air. Battery systems currently under investigation include magnesium/sulphur and aluminium/graphite fluoride. However, future use in EVs depends on significant technological improvement and practical viability of these systems.

9 Challenges

India's transportation sector should address the dual necessities of nation's economic growth and environmental sustainability. Transport decarbonisation is essential to meet the climate goals under international commitments; however, this task is fraught with challenges. India's diverse geography, expanding urban population and motorization, and reliance on fossil fuels pose significant hurdles. For a cleaner and more efficient transport sector; technical infrastructural, and socio-economic changes are required, along with policy reforms, investments in green technologies, and behavioural changes. This chapter delves into the complexities and multifaceted nature of transport decarbonisation, highlighting the critical obstacles and the potential pathways to achieving a sustainable transportation.

9.1 Biofuel Blending

9.1.1 Ethanol

The major challenge concerning the utilisation of ethanol in transport sector is related to the food vs fuel debate i.e., feedstock availability for ethanol production. Although India has been on the path of achieving self-sufficiency in foodgrain demand and sugar with a significant push on production in comparison with consumption in recent years, output decreases due to weather-related factors have the potential to disturb the consistent availability of sufficient supply of cereal and sugarcane-based raw materials (Nouni et al., 2021). During sugar season of 2019–20, approximately 9 lakh metric tons of sugar were redirected towards ethanol production (Ministry of Consumer Affairs, Food & Public Distribution, 2021). Sugarcane juice and B-heavy molasses constituted 69 percent of the feedstock for ethanol in ESY 2023 (ICRA, 2023).

There have been imbalances on both supply and demand fronts. Based on expected declines in sugar production due to insufficient rainfall in key growing areas, the Government of India had initially directed all sugar mills and distilleries to avoid using sugarcane juice or sugar syrup for ethanol production during the 2023-24 ethanol supply year (ESY), permitted only B-heavy molasses (ET, 2023). This order was however, reversed, under industry push, with a sugar diversion cap of 17 lakh tonnes for ESY 2023-24 (ET, 2023). The government anticipated decline in sugar production. Despite this, the stock of biofuel with ethanol distilleries is rising due to lack of purchases from OMCs, who claim to buy enough to fulfil the 15 percent blend target (ET, 2024).

9.1.2 Biodiesel vs Compressed Biogas

Biodiesel blending for on-road diesel was estimated to be only 0.07 percentage in 2022 (USDA, 2022) and meeting the 5 percent target by 2030 seems a little farfetched. The share of non-edible industrial feedstock for fuel use is estimated to be 59 percent in 2022 (USDA, 2022). Inadequate production of biodiesel is often linked to insufficient availability of these non-edible seed crops primarily stemming from the absence of adequate incentives for farmers to cultivate them (Nouni et al., 2021). This is followed by used cooking oil (UCO) (38 percent) and then animal fats and tallows (3 percent) (USDA, 2022). Palm stearin has been a favoured source for feedstock production in the country for quite some time due to its high yield which makes it suitable for large-scale production without requiring upgradation in production plants (Jamal, 2023). However, only 3.7 lakh hectares of land is used for palm oil cultivation in the country and 98 percent of the crude palm oil being imported (Jamal, 2023).

Compressed biogas (CBG) would be preferred over biodiesel as feedstock collection process would be easier in case of CBG with establishment of city-based plants. Significant abundance of waste organic biomass in a developing country like India presents feedstock preferences for CBG plants (Singh et al., 2023). This includes agricultural residues, animal waste, press-mud, municipal solid waste (MSW), and sewage sludge (Singh et al., 2023). Fifty percent of generated MSW is disposed in landfills constituting about 45–55 percent of organic fraction that could be utilised for CBG plants (Singh et al., 2023).

9.1.3 Sustainable Aviation Fuel (SAF)

The potential challenges that could cause barriers to penetration of SAF in India include finance barriers. At present, the cost of SAF is approximately 3 to 5 times higher than the cost of traditional fossil aviation turbine fuel (ATF), depending on the feedstock and production pathway employed (ICAO, 2023). The absence of sufficient infrastructure and a supportive ecosystem further contributes to the overall cost of SAF (ICAO, 2023). Establishing SAF production facilities necessitates significant initial investments, and obtaining financing, particularly in the early stages of development, can pose a potential barrier (ICAO, 2023). Secondly, on feedstock fronts, the limited potential for hydro processed esters and fatty acids (HEFA) based sustainable aviation fuel (SAF), which is currently the most cost-effective pathway, in India poses a risk to the country's cost competitiveness (ICAO, 2023).

9.2 Battery Electric Vehicles: Issues with Battery Recycling

EVs are locally non-polluting hence considered to meet some of the environmental challenges of current road transport system. However, EV batteries contain potentially scarce or toxic metals, such as copper, lithium, nickel, cobalt, and graphite. Hence, large-scale EV adoption would introduce resource constraints and have detrimental environmental effects (Rade & Andersson, 2001). There is an increased mining and processing of these critical minerals to support the clean energy transition as 139,600 tonnes of processed lithium were produced from the lithium triangle – Argentina, Chile, and Bolivia and Australia in 2020 (Adams, 2021). The annual trade in critical minerals increased from USD 53 billion to USD 378 billion in the last two decades.[70] However, the high demand for energy-related critical minerals would put pressure on the supply chains; therefore, a steady supply will be important. Moreover, in the midstream, refined lithium is required for EV batteries, which is concentrated in China with approximately 65 percent of the world's lithium processing capacity (Brunelli, et al., 2023).

As EV adoption increases and the vehicles reach end-of-life, the battery-recycling market would expand. EV battery recycling and material recovery would keep toxic materials from entering the waste stream, both at the end of useful life and during production.[64] The recycling and material recovery would reintroduce these critical materials back into the supply chain and ensure supply chain sustainability and resilience.

Most components of Li-ion batteries can be recycled but cost of material recovery and inefficiency of traditional lithium extraction methods remains as challenges. The 2006 European Union Directive on Batteries and Accumulators established collection rates of at least 25 percent

[70] https://www.wto.org/english/blogs_e/data_blog_e/blog_dta_10jan24_e.htm

and 45 percent by September 26, 2012, and September 26, 2016, respectively. Additionally, recycling targets were defined as about 65 percent, 75 percent, and 50 percent of the weight of battery for nickel-cadmium, lead-acid, and other battery chemistries, respectively.[71] There are technologies such as direct lithium extraction which has shown lithium recovery rate of 90 percent (EV Markets Reports, 2024).

Accelerating innovation of advanced battery technologies which require less quantity of critical minerals, uptake of vehicle models with optimised battery size, and the development of battery recycling can ensure sustainable supply of critical minerals.

9.3 Potential for Hydrogen as Alternative Fuel

Hydrogen as a fuel has the potential for near-zero greenhouse gas emissions, as it generates electrical power in a fuel cell, emits only water vapour and warm air. The production process of hydrogen should also have minimal or no carbon emissions to meet the demand for green hydrogen sustainably. However, there are commercialisation challenges associated with fuel storage, production, infrastructure requirements, high capital, operational, and maintenance costs for adoption of the technology, and supply chain development.

Green hydrogen is commonly produced by either electrolysis, steam reforming, or fermentation. In electrolysis, electricity is used to split water into hydrogen and oxygen with an efficiency of around 60 – 80 percent by calorific value. Challenges associated with this process are overall improvement in energy efficiency, requirement of additional onsite compressors, and less than 5 years lifetime of electrolysers (Bhagavathy & Thakur, 2021).

Hydrogen's energy content by volume is low; therefore, compact storage of hydrogen requires high pressures, low temperatures, or chemical processes. Overcoming this challenge is important for LDVs because of limited size and weight capacity for fuel storage and even though MHDVs have larger tanks but it would reduce total payload capacity.[72] Unlike an EV battery, where major cost is constituted by the critical minerals as raw materials, the major cost of a fuel cell is manufacturing of the fuel cell stack. Hydrogen-based Fuel Cell EVs have higher efficiency than ICE vehicles, long driving range, and no emissions; however, end-use challenge of high complexity of thermal and water management, purification, and humidification in a fuel cell need to be addressed.

The infrastructure cost to build and maintain hydrogen stations should also reduce to support a hydrogen economy. The common methods of transport and distribution of hydrogen are pipelines, high-pressure tube trailers, and liquified hydrogen tankers (Bhagavathy & Thakur, 2021). Transportation in liquified hydrogen tankers is more efficient for than transportation by high-pressure tube trailers as increases the density of distributed hydrogen. However, the compressed hydrogen is at a risk of evaporating and causing significant losses and ineffective utilization.

Green hydrogen has the potential to decarbonise the transport sector, especially in hard-to-abate areas such as heavy-duty transport, however, challenges need to be addressed.

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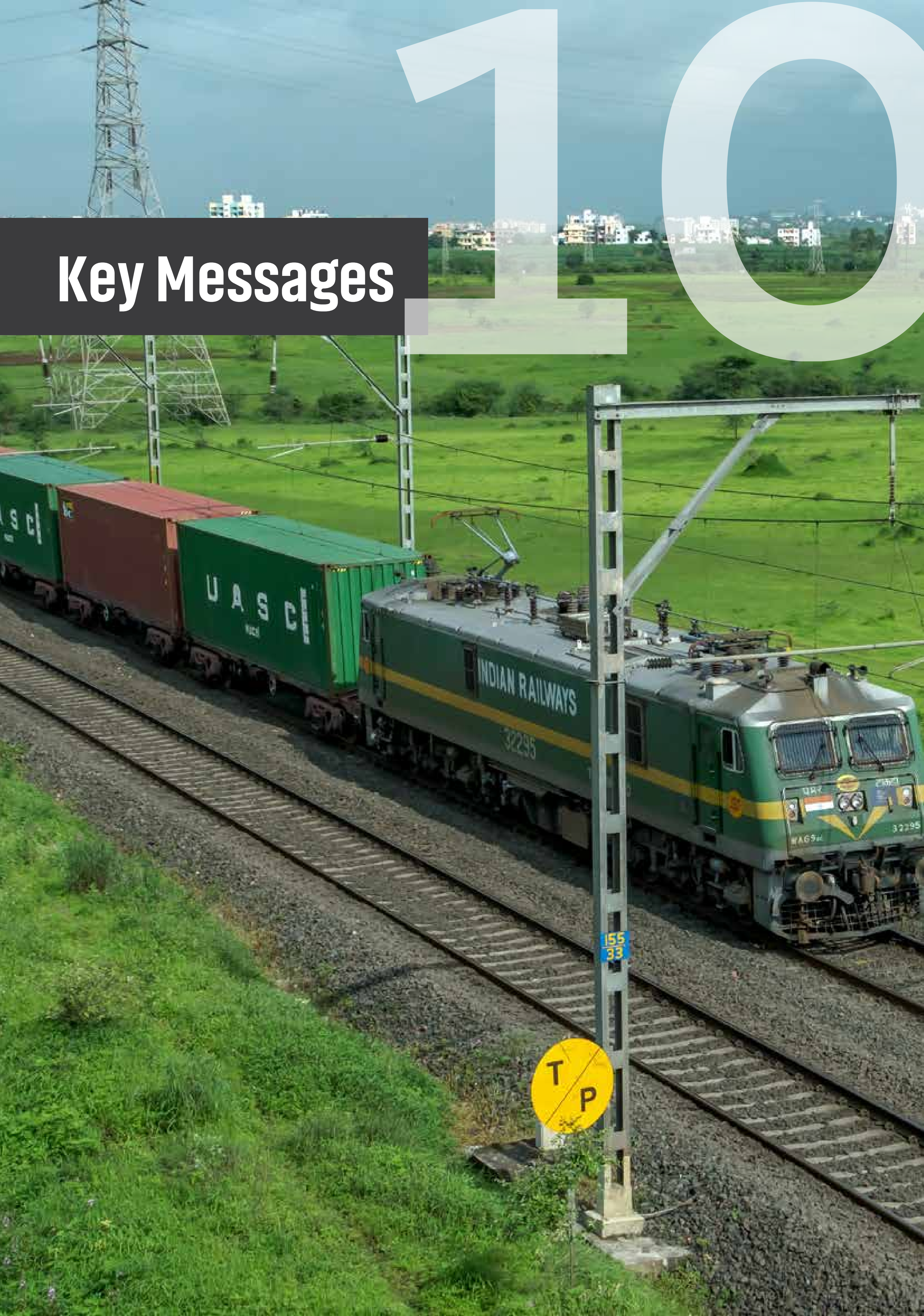
71 https://archive.epa.gov/oswer/international/web/pdf/200806_batteries_eu_directive.pdf

72 https://afdc.energy.gov/fuels/hydrogen_benefits.html#:~:text=Fuel%20Storage&text=This%20makes%20storing%20hydrogen%20a,weight%20capacity%20for%20fuel%20storage.

10 Key Messages



The transport demand in India will increase with the rising GDP and per capita income

Total per capita passenger transport demand is expected to grow to 9,202 passenger kilometres (PKM) in 2030–31, 16,152 PKM in 2050–51, and 20,283 PKM in 2070–71, from 5,280 PKM in 2019–20.

Road transport

- Passenger vehicles are expected to grow to 451 million (2.3 times) in 2030–31, 794 million (4.1 times) in 2050–51, and 897 million (4.6 times) in 2070–71, as compared to 193 million in 2019–20. The corresponding passenger transport demand by road (in terms of billion passenger kilometres, BPKM) is expected to grow to 11,406 (1.9 times) in 2030–31, 22,630 (3.7 times) in 2050–51, and 29,251 (4.8 times) in 2070–71 as compared to 6,098 in 2019–20.
- The share of road transport is projected to be 85 percent of the total passenger transport demand.
- Per capita passenger road-based transport demand (in terms of PKM) is expected to grow to 7,529 (1.7 times) in 2030–31, 13,547 in 2050–51 (3.1 times) and 17,306 in 2070–71 (3.9 times) as compared to 4,409 in 2019–20.
- Freight vehicles are expected to grow to 24 million (2.2 times) in 2030–31, 53 million (5 times) in 2050–51, and 69 million (6.5 times) in 2070–71 as compared to 11 million in 2019–20. The corresponding freight transport by road (in terms of billion tonne km, BTKM) is expected to grow to 6,173 (3.1 times) in 2030–31, 18,876 (9.6 times) in 2050–51, and 29,766 (15.1 times) in 2070–71 as compared to 1,974 in 2019–20.

Rail transport

- Passenger transport via rail (in terms of BPKM) is expected to grow to 1,985 (1.9 times) in 2030–31, 3,132 (2.9 times) in 2050–51, and 3,754 (3.5 times) in 2070–71 as compared to 1,069 in 2019–20.
- Freight transport via rail (in terms of BTKM) is expected to grow to 1,085 (1.5 times) in 2030–31, 1,762 (2.5 times) in 2050–51, and 2,592 (3.7 times) in 2070–71 as compared to 708 in 2019–20.

Domestic aviation transport

- Domestic air passenger transport (in terms of BPKM) is expected to grow to 550 (4 times) in 2030–31, 1,221 (8.9 times) in 2050–51, and 1,280 (9.4 times) in 2070–71 as compared to 137 in 2019–20.
- Freight transport via domestic aviation is expected to grow from a meagre 1 BTKM in 2019–20 to 6 BTKM in 2050–51 and 12 BTKM in 2070–71.
- With passenger transport demand being driven massively by private ownership of vehicles, especially cars and jeeps, it becomes extremely important to act towards encouraging public transport. Public transport in India is plagued by 'crowding externalities' (one person's decision to opt for public transport reduces the utility of another person in terms of discomfort, unsafe environment, etc.). The Government and private players must collaborate extensively to improve the frequency and scale of public transport services to reduce traffic congestion, overcrowding, and ensure social and environmental gains for all.

With the increasing transport demand and corresponding rising fuel demand, the emphasis for transport decarbonisation lies in the increased adoption of cleaner fuels

Fossil fuels

The three provide significant opportunities for a reduction in demand for petroleum products in comparison to the baseline demand projections. Consequently, increased use of natural gas also provides an expanding opportunity, portraying a substitution from primarily a petroleum-based to a gas-based transportation.

- In 2070-71, petrol and diesel are expected to decline by 74 percent and 56 percent in policy in action (PIA) as compared to baseline scenario.
- Comparing the pathways in the ambitious scenario to baseline, the petrol would decline by 76–100 percent and diesel would decline by 64–78 percent. In the pathways of highly ambitious scenario, petrol would decline by 85–100 percent and diesel would decline by 91–96 percent as compared to the baseline scenario.
- Natural gas is expected to increase by 75 percent in PIA and 26–129 percent in ambitious scenario as compared to the baseline scenario. And in case of highly ambitious scenario, it is likely to increase by 20 percent (in pathway 1– unconstrained supply of natural gas) and decrease by 24 percent (in pathway 2– supply and cost constraints of natural gas) as compared to the baseline scenario.
- **Fossil fuel will continue to play important role in India's transport sector,** though alternative fuel technologies will grow manyfold. Even under the Highly Ambitious scenario, the fossil fuel demand for transportation will start declining starting 2050–51 and reaching below the 2030–31 demand level by 2070–71.
- Natural gas will dominate the fossil fuel demand for transport sector, replacing the usage of petroleum products.

Electricity

The total estimated electricity demand (in terawatt-hour, TWh) from transport for selected years under the four scenarios (baseline, PIA, Ambitious, and Highly Ambitious) is shown in Table 10.1.

Table 10.1: Total electricity demand (in TWh) for transport

	Baseline	PIA	Ambitious	Highly Ambitious
2020–21	11.5	11.5	11.5	11.5
2030–31	37.2	67.8	67.8	67.4
2050–51	114.6	401.9	518.2	602.4
2070–71	275.5	870.9	1,138.5	1,578.3

Source: TERI

- The share of road transport in total electricity demand from Indian transport is expected to increase from 7 in 2020-21 to 84–97 percent in 2070-71 (The lower limit represents the baseline scenario, and the upper limit represents the Highly Ambitious scenario), with no exogenous change in rail freight share.
- The total electric vehicle (EV) projection ranges between 220– 858 million units, and the corresponding EV battery demand ranges between 4.5–23.5 TWh by 2070–71 in the four scenarios.
- With the increasing adoption of EVs across the passenger segments, around 70 percent of the battery energy demand would be from passenger transport, particularly from 4Ws.
- Medium and heavy goods vehicles (MHGV) will drive the demand for EV battery energy requirement in the freight segment, i.e., 10-29 percent of the total road transport battery demand.
- In lithium-ion nickel manganese cobalt (NMC) batteries, among the critical minerals, nickel requirement is highest with 72 percent of the total mineral requirement for the cathode, followed by lithium, i.e., 11 percent, and 9 percent cobalt and manganese.
- Corresponding to EVs on-road, the lithium demand in PIA would be 201 percent higher in the Ambitious scenario 287 percent higher, and in Highly Ambitious scenario 425 percent higher compared to the baseline scenario. The supply chain of critical minerals can be made circular through cost-effective battery recycling technologies.

With electrification increasing rapidly, solar charging stations are being explored globally which would imply zero carbon emissions throughout the well-to-wheel journey. Additionally, it will bring down the burden on the grid, especially during peak hours. Solar charging in residential spaces should be explored with a low levelized cost of electricity in India offering cost effectiveness for home-based EV charging. This would however be effective with battery technologies being able to store energy beyond solar hours and should be encouraged at varying levels based on local climactic conditions. A careful study needs to be undertaken to assess the additional battery requirement and its impact on critical minerals and recycling.

Hydrogen

The total estimated green hydrogen demand (in million metric tonnes, MMT) from transport for selected years under the three scenarios is shown in Table 10.2. The National Green Hydrogen Mission of 2023 envisages an annual production of 5 MMT by 2030 and the transport sector is projected to contribute to this demand by 0.7 percent in PIA and 3.4 percent in Ambitious and Highly Ambitious scenarios.

The adoption path of hydrogen as fuel is likely to start with the use of grey hydrogen at the beginning, to capitalise on its cheaper cost of production, followed by use of blue hydrogen in the medium-run, ultimately transitioning to green hydrogen as the prices become cheaper in the long-run.

Table 10.2: Total hydrogen demand (in MMT)

	Baseline	PIA	Ambitious	Highly Ambitious
2020–21	0	0	0	0
2030–31	0	0.04	0.2	0.2
2050–51	0	2.1	4.6	9.7
2070–71	0	20.0	26.0	44.1

Source: TERI

Supply chain security through international collaboration for fuel and critical minerals for fuel cells needs to be strengthened where much of it is imported. The fuel cell technology is at a very nascent stage. For a transition to EVs, scaled-up demand incentives should be guaranteed for considerable periods, post pilots, across all stakeholders, to minimize investment risks.

Biofuels requirements

The requirement for different biofuels has been represented in Table 10.3.

- It can be seen with electrification and transition to green hydrogen, the requirement for ethanol and biodiesel in transport will fall as the overall petrol and diesel demand is expected to decline.
- With the increase in gas-based transportation, the compressed biogas (CBG) requirement is likely to expand significantly. However, with constraints on supply of gas based on implicit considerations of production cost and import of gas, thereby, reducing the cost advantage of gas, the CBG requirement would be low as well. This would take place with sustained requirement of ethanol and biodiesel, varying on the level of uptake of electrification and green hydrogen (as indicated by the differences in Pathway 2 of Ambitious and Highly Ambitious scenarios).
- Also, with an increase in demand for domestic air transport, Sustainable Aviation Fuel (SAF) is going to play a key role in the decarbonisation of domestic aviation in India.

Table 10.3: Biofuel requirement in different scenarios

	Ethanol (billion litres)						Biodiesel (billion litres)						CBG (billion kg)						Sustainable Aviation Fuel (SAF) (billion litres)		
	BL	PIA	AMB		HA		BL	PIA	AMB		HA		BL	PIA	AMB		HA		BL	PIA	AMB/ HA
			P1	P2	P1	P2			P1	P2	P1	P2			P1	P2	P1	P2			
2020–21	4.3	4.3	4.3	4.3	4.3	4.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030–31	9.5	17.5	17.5	17.5	17.5	17.5	0	7.8	7.4	7.6	7.4	7.5	0	0.7	0.9	0.8	0.9	0.8	0	0.4	0.4
2050–51	16.8	22.6	17.3	19.9	14.0	16.9	0	13.0	20.8	23.6	17.2	19.7	0	4.0	9.4	7.3	9.2	7.2	0	0.9	8.9
2070–71	16.0	8.3	0	7.7	0	4.9	0	10.3	10.1	17	1.7	4.0	0	6.5	20.2	13.7	8.4	5.1	0	0.8	20

Note: BL- Baseline; PIA- Policy-in-action; AMB- Ambitious; HA- Highly Ambitious; P1- Pathway 1; P2- Pathway 2.

Source: TERI

Infrastructure development needs to be put into action extensively by all stakeholders to meet the biofuel blending mandates. Long-term data inventories based on forecasts should be prepared for biofuel requirements to manage food security, resource availability, and livelihoods.

GHG emission reduction

The three scenarios, PIA, Ambitious, and Highly Ambitious are based on increased electrification, adoption of green hydrogen, uptake of biofuel blends, and improvements in fuel efficiency across different modes of transport and are estimated to result in GHG emission reduction (well-to-wheel) of 6 percent in 2030–31; 19, 30–31, and 36 percent in 2050–51; and 40, 54–56, and 77–78 percent in 2070–71.

Increasing importance of rail share in freight transport for transport decarbonisation

The total freight transport demand is expected to grow by 1.7 times in 2030–31, 6.7 times in 2050–51, and 11 times in 2070–71, from 2,682 PKM in 2019–20. However, with this rising freight demand, the share of road freight share would increase from 73 percent in 2019–20 to 85 percent in 2030–31. Keeping in mind the overall importance of rail in transport decarbonisation, Indian Railways have undertaken initiatives to increase rail share in freight transport in the National Rail Plan for 2030.

- With an exogenous assumption on rise in the share of railways to 35 percent in 2030–31 and 45 percent by 2040–41, an additional emission reduction of 18.8 percent in 2050–51 and 22.4 percent in 2070–71 can be achieved in PIA scenario. Further, if aggressive attempts are undertaken to expand rail freight share to 45 percent in 2030–31 and 50 percent by 2040–41, it could result in additional GHG emission reduction of 21 percent in 2050–51 and 26 percent in 2070–71 in the Ambitious and Highly Ambitious scenarios.
- Railway Board needs to reform freight pricing system to make it more competitive, reduce terminal detentions, provide assured and timely delivery of goods, improve terminal infrastructure, etc. to attract freight traffic (TERI, 2023).

Coastal shipping

With expanding trade, the maritime industry (both coastal and international shipping) is going to play a crucial role in the transport of cargo movement.

- With the increase in economic activity, coastal cargo traffic is expected to grow to 1.7 times in 2030–31, as compared to 2021–22.
- In Indian coastal shipping, liquefied natural gas (LNG) and derivatives of green hydrogen like green ammonia/green methanol are going to be key players in the decarbonisation of shipping. It is expected that the adoption of LNG and green ammonia could result in a GHG emission reduction (well-to-wake) of 7.5 percent in 2030–31 compared to the baseline scenario. The emphasis forward is expected to be on derivatives of green hydrogen and LNG is likely to act as a transition fuel due to high GHG emissions in terms of complete life cycle.

Further, with initiatives under the National Green Hydrogen Mission for the development of bunkering and refuelling facilities for green hydrogen picking up, India has the potential to act as a refuelling hub for green hydrogen and/or its derivatives.

Overall transport decarbonisation

With increasing transport demand, even in the Highly Ambitious scenario, the GHG emissions would increase 39–42 percent, from 391 million tonnes of CO_2e in 2019–20 to 535–553 million tonnes of CO_2e in 2070–71. The transport sector, which is hard-to-abate would not be able to achieve net-zero emission target by 2070–71, in isolation. Carbon credits, carbon offsetting measures, and combined efforts from different sectors of the economy should be adopted to achieve net-zero for the inevitable carbon emissions from the transport sector.

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Annexure

Table A.1: Targeted number of responses – Field survey

City Clusters	2W	3W (P)	3W(G)	4W- Cars and Jeeps	4W- Taxi	LGV (4W)	MHGV	Total
Lucknow, NOIDA, Ghaziabad	81	42	9	51	2	50	51	287
Mumbai	57	60	7	68	4	73	61	329
Chennai	57	41	5	42	3	70	57	273
Bengaluru	49	58	16	50	5	54	58	290
Ahmedabad	37	46	19	46	1	37	47	233
Bhopal	35	16	7	20	1	21	25	125
Hyderabad	26	34	0	24	2	29	28	142
Kolkata	26	12	5	21	2	32	45	143
Delhi	21	19	7	48	2	24	8	128
Ludhiana	22	7	1	27	1	20	21	99
Bhubaneshwar	20	16	5	8	1	16	31	97
Guwahati	9	8	3	11	1	15	8	54
ALL	**440**	**357**	**83**	**415**	**25**	**440**	**440**	**2,200**

Table A.2: Distribution of the responses– Field and online surveys

Types of Operation	Passenger Vehicles (PV)									Goods Vehicles (GV)				Sum Total of All
	2W			3W-P	4W-C&J			4W-Taxi	Total of PV	LGV [≤7.5 Tonnes]	MGV [>7.5 BUT ≤12 Tonnes]	HGV [>12 Tonnes]	Total of GV	
	Field Survey	Online Survey	Total		Field Survey	Online Survey	Total							
Inter-city	178	9	187	147	242	3	245	27	607	191	41	227	459	1,065
Intra-city	212	78	290	158	119	137	256	8	712	223	19	36	278	990
TOTAL	**390**	**87**	**477**	**306**	**361**	**140**	**501**	**35**	**1,319**	**414**	**60**	**263**	**737**	**2,055**

Figure A1: Photos of the Field Survey Conducted

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