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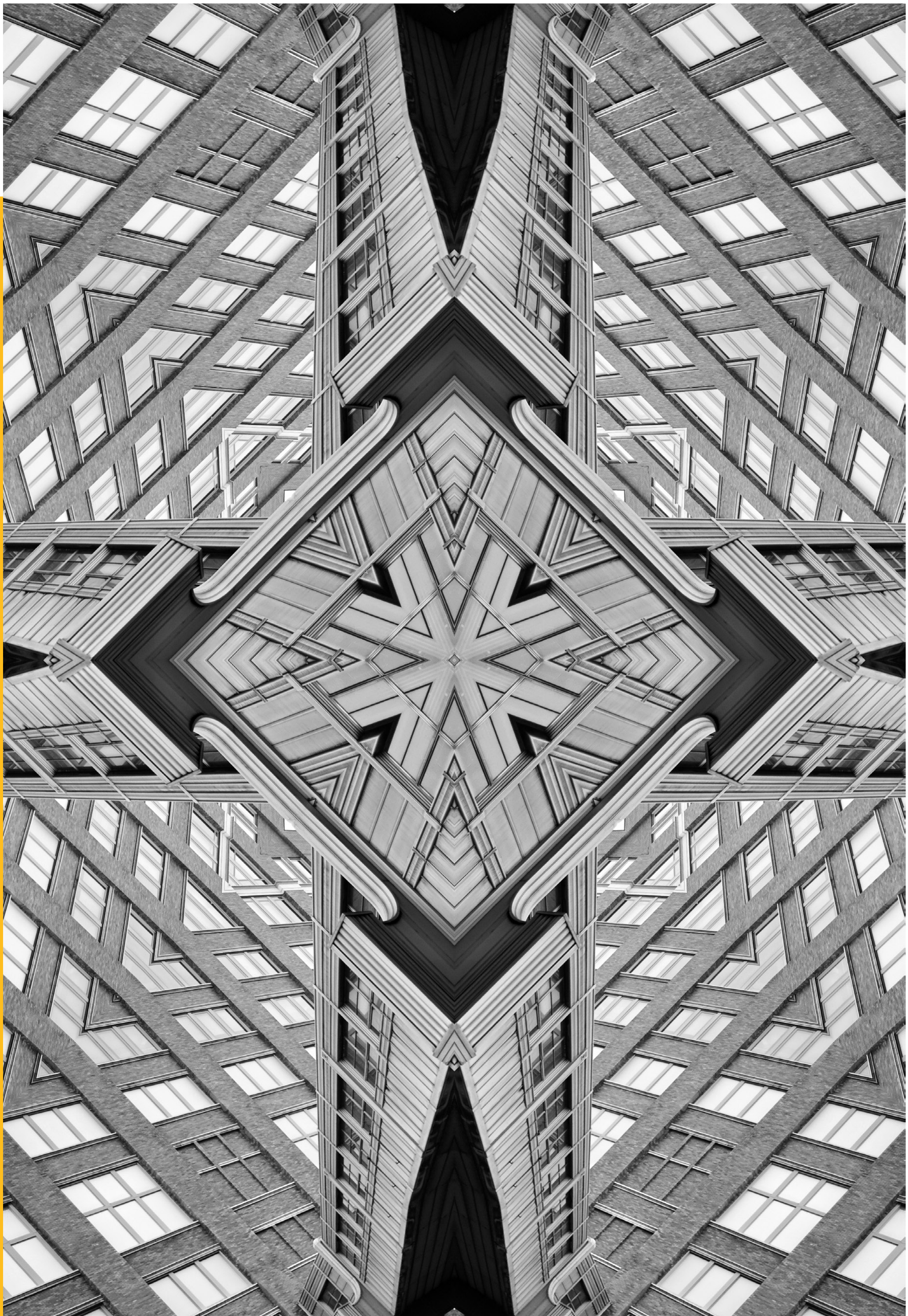

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Energy Transition in India's Transport Sector: Current Policies, Key Challenges, and Potential Pathways

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Abstract

The increasing demand for mobility and the rising rates of motorisation in India have substantially increased energy consumption and carbon dioxide (CO_2) emissions from the road transport sector. As of 2021, road transport was responsible for 14 percent of the nation's total energy consumption, 92 percent of transport-related energy demand, and 94 percent of transport-related CO_2 emissions. In 2021, India committed to net-zero carbon emissions by 2070, making the need to decarbonise the transport sector more urgent. This study utilises a review of literature on the trajectories of decarbonisation and energy transition in India's transport sector. It analyses projections of current and future energy requirements and CO_2 emissions; identifies social, infrastructural, institutional, financial, and policy barriers to a sustainable energy transition; and recommends policy interventions.

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Introduction

Rapid urbanisation has led to a massive increase in India's urban population,[1] with the urbanisation rate reaching 31.60 percent in 2011 from 25.7 percent in 1991. By 2030, the urban population is projected to reach 600 million, up from 377 million in 2011.[2] The contribution of urban areas to the country's gross domestic product (GDP) is pegged to increase from 63 percent in 2019 to 75 percent in 2030.[3]

Urbanisation patterns, however, vary across regions,[4] with the lowest rate in Himachal Pradesh at 10 percent and the highest in Tamil Nadu at 48.4 percent. These disparities should be considered in the management of urban areas.[5]

Higher purchasing power, in parallel to the availability of affordable personal transport modes, have contributed to the increase in the number of private automobiles in cities;[a] road traffic volumes have risen, as a result. The number of registered motor vehicles increased from 114.95 million in 2009 to 295.8 million in 2019, recording a compound annual growth rate (CAGR) of 9.91 percent over those 10 years—this outpaces the CAGR of national highways of 5.54 percent over the same period.[b,6] Meanwhile, the share of public transport vehicles, especially buses, is negligible in most Indian cities (see Table 1). India had approximately 60 million cars by 2020, with projections indicating this figure could reach 262 million by 2050.[7]

Table 1: Vehicular Growth Rate in India (1951-2020)

Year	Two-Wheelers	Cars, Jeeps & Taxis	Buses	Goods Vehicles	Others	Total (Million)
	(as % of total vehicle population)					
1951	8.8	52.0	11.1	26.8	1.3	0.3
1961	13.2	46.6	8.6	25.3	6.3	0.7
1971	30.9	36.6	5.0	18.4	9.1	1.9

a This refers to both two-wheelers and four-wheelers.

b Two-wheelers accounted for 75 percent of registered vehicles in 2020, recording a CAGR of 10.47 percent across the previous 10 years, followed by four-wheelers, with 10.29 percent CAGR.

Year	Two-Wheelers	Cars, Jeeps & Taxis	Buses	Goods Vehicles	Others	Total (Million)
	(as % of total vehicle population)					
1981	48.6	21.5	3.0	10.3	16.6	5.4
1991	66.4	13.8	1.5	6.3	11.9	21.4
2001	70.1	12.8	1.2	5.4	10.5	55.0
2011	71.8	13.6	1.1	5.0	8.5	141.8
2017	73.86	13.30	0.74	4.84	7.27	253.0
2018	74.40	13.37	0.71	4.69	6.85	272.60
2019	74.8	12.99	0.69	4.65	6.85	295.8
2020	74.6	13.37	0.67	4.37	6.89	326.3

Source: Author's own, using data from MoRTH Handbook 2020-21.[8]

In 2020-21, among the 55 cities in the country with a population of more than 1 million, Delhi had the highest number of registered motor vehicles (11.893 million), followed by Bengaluru (9.638 million), Faridabad (8.6 million), Chennai (6.352 million), Ahmedabad (4.571 million), Greater Mumbai (3.876 million), and Surat (3.562 million).[c] These seven cities alone accounted for 45.5 percent of the total annual registration of vehicles. Country-wide, two-wheelers accounted for 75 percent of the total registered vehicles in 2020, compared to a paltry 8.8 percent in 1951. Conversely, even as their absolute numbers have grown substantially, the combined share of cars, jeeps, and taxis among registered vehicles has declined from 52 percent in 1951 to 13.37 percent in March 2018 and 12.99 percent in March 2019. The share of buses too, has declined from 11.1 percent in 1951 to 0.71 percent in 2018 and 0.69 percent in 2019,[9] indicating higher dependence on private vehicles.

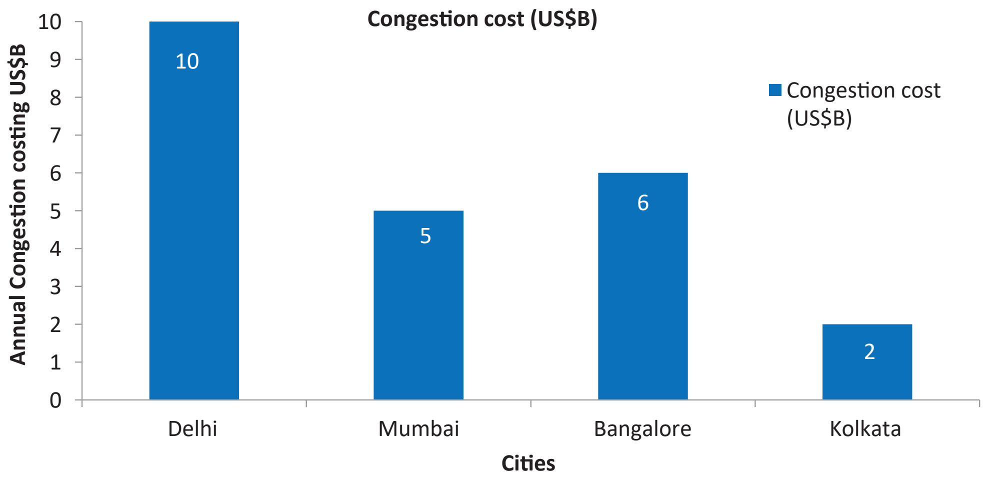
Over the years, the government has augmented road carriage capacity by constructing flyovers and widening existing roads. It has, however, failed to simultaneously augment the capacity, frequency, accessibility, and first- and last-mile connectivity of public transportation systems to meet the increased demand for travel. This has triggered a massive increase in the

c Two of the country's biggest cities, Mumbai and Kolkata, no longer figure among the top five in the list of cities with the greatest numbers of registered vehicles. Greater Mumbai with 3.8 million vehicles (as of March 2020) is 6th, while Kolkata with 1.02 million, is 32nd.

use of personal transport modes, leading to increased traffic congestion, road accidents, poor peak hour travel experience, and environmental degradation.[10]

The increase in transport modes has raised the per capita trip rate, which is estimated to grow even further in the coming years—from 0.8-1.55 in 2007 to 1-2 by 2030—unless there is urgent policy intervention.[11] Consequently, the speed of public transport is expected to decrease from 26-17 km per hour to 8-6 km per hour.[12] The resulting higher congestion costs will reduce productivity, increase economic losses, and fuel wastage. In 2018, four metro cities in India lost US$22 billion due to congestion. In Delhi, congestion is estimated to be costing the city US$ 9.6 billion (~12 percent of its GDP) annually in fuel waste, reduced productivity, air pollution, and accidents.[13] Figure 1 shows the high-level congestion in four metro cities in India.

Figure 1: Congestion Cost in Metropolitan Cities of India



Source: Unlocking Cities: Impact of Ridesharing Across India.[14]

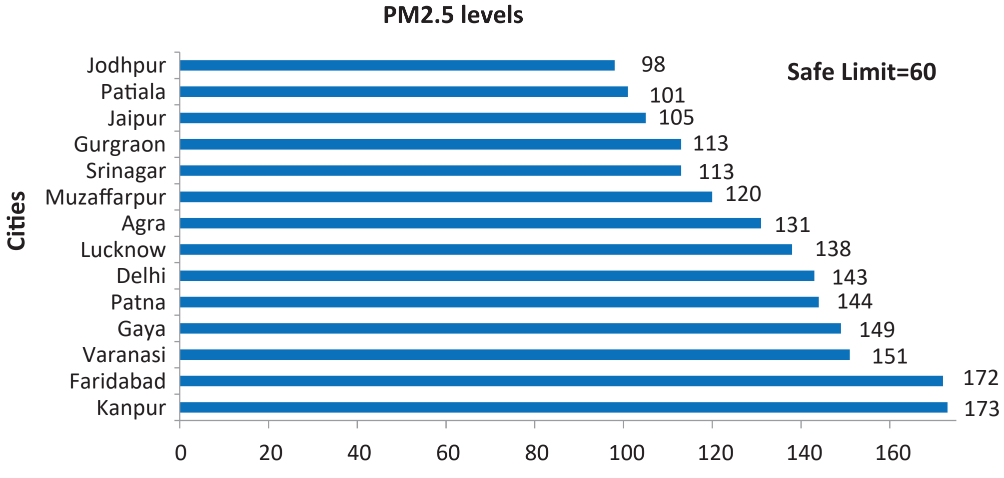
Introduction

According to the World Air Quality Report (2019), 21 of the world's 30 most polluted cities are in India.[15] The transport sector is a major contributor to air pollution.[16] The primary pollutants emitted by vehicles, including carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx) and particulate matter (PM), account for about 11 percent of India's carbon emissions. .

In 2018, India's urban pollution, measured by PM 2.5 (one of the main forms of PM and a key indicator), was 40 percent above the safe limit across major Indian cities, as shown in Figure 2.[17] A study by the Central Pollution Control Board (CPCB) of PM levels in six cities—Delhi, Kanpur, Bangalore, Pune, Chennai, and Mumbai—showed that transportation contributes 30 and 50 percent of PM pollution in these areas, both through direct vehicular emissions and the re-suspension of road dust caused by vehicular traffic.[18]

Road transportation-related air pollution impacts human health, agriculture, ecology, buildings, and climate. It is also a growing cause of respiratory, cardio-vascular, cardio-pulmonary, and reproductive system ailments, and can lead to certain cancers.[19] A 2021 report by the Boston-based Health Effects Institute underlined how particulate matter pollution causes more than 1.24 million—or 12.5 percent—of total deaths in India annually.[20] Indeed, in 2015, India reported 74,000 premature deaths attributed to transport pollution, 1,800 of them from New Delhi.[21] Further escalation in transport emissions will exacerbate these challenges, adding greater strain to an already overwhelmed public health infrastructure.

Figure 2: PM2.5 Levels in Big Indian Cities



Source: India Air Quality Index[22]

Introduction

Road transport consumes 92 percent of India's transportation sector's total energy, with rail and domestic aviation accounting equally for the remaining 8 percent. While transportation currently contributes 14 percent to India's energy-related CO_2 emissions, the figure is bound to increase with vehicle fleet growth, which currently is relatively small in proportion to its large population.[23] The demand for internal combustion engine (ICE) vehicles has more than doubled since 2000.[24] Similarly, the surge in freight transport in India (increasing 10-fold since the 1990s), primarily driven by ICE heavy-duty vehicles (HDVs), will further increase the sector's fossil fuel demand, which is already the world's highest.[25]

India's energy consumption is thus projected to experience significant growth, with primary energy demand doubling to approximately 38.5 million barrels of oil equivalent per day (mboe/d) by 2045. While renewable energy is expected to be the fastest growing energy source at 11.5 percent, fossil fuels will remain dominant, with oil and coal comprising approximately 30.1 percent and 33.2 percent of the energy mix, respectively, as per projections from the Petroleum Planning and Analysis Cell (PPAC).[26]

Oil demand is expected to more than double from 5.1 mboe per day in 2022 to 11.6 mboe per day by 2045. Due to limited domestic production, India's reliance on oil imports is projected to exceed 90 percent by 2030, and in the case of gas, over 60 percent. India's annual energy import bill already surpasses US$160 billion. If business as usual (BAU) continues, this figure is likely to double within the next 15 years. This escalating import burden is a massive financial challenge.[27]

Transforming the energy profile of the transport sector can mitigate all these challenges. Electric vehicle (EV) adoption in Beijing, China, for instance, led to PM2.5 levels there dropping by 35 percent between 2012 and 2017. It also reduced urban heat island intensity by 0.94°C. Indeed, it is projected that a complete replacement of ICE vehicles with EVs in the city would result in daily energy savings of approximately 14.44 million kilowatt hours (kWh) and a reduction in daily CO_2 emissions by 10,686 tonnes.[28] A case study from Copenhagen, meanwhile, recognised as one of the most bicycle-friendly cities globally, showed that over a decade, its investment in cycling infrastructure has increased bicycle commutes from 35 percent to

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49 percent, which has both reduced carbon emissions and improved urban air quality.[29] In India too, a 2023 joint report by the International Energy Agency (IEA) and NITI Aayog noted that strictly implementing Bharat Stage (BS) emission standards and transitioning to EVs would reduce NOx emissions by 15-20 percent by 2030.[30]

Using data culled by different agencies, this paper seeks to understand and delineate the trajectory of energy transition and decarbonisation in India's transport sector. It examines the present and future projections of transportation energy requirements and their externalities, identifies the barriers to a smooth transition to sustainable energy, and recommends policy interventions to facilitate the sector's energy transition by 2070, the year by which India committed to achieving 'net-zero' emissions.[31] It reviews existing models for energy transition and decarbonisation, analysing previous frameworks and methodologies to highlight critical impediments, and outlines actionable policies to achieve sectoral goals.

Current Realities and Future Projections

Road transport is India's largest consumer of oil, its share in 2021 being 44 percent. Almost all its energy requirement—95 percent—is met by petrol and diesel, with alternative fuel sources such as natural gas and bio-fuels contributing just the remaining 5 percent.[32] Both the energy demand and carbon emissions of the road transport sector have more than trebled since the start of the 21st century. Its carbon emissions comprise 12 percent of total emissions, per capita emission by this sector having risen two and a half times since 2000.[33] Segment-wise, in 2021, trucks accounted for 38 percent of both fuel consumption and carbon emissions, cars 25 percent, and two- and three-wheelers 20 percent. Such is the distribution despite two and three-wheelers comprising 80 percent of vehicle stock, though in their case too, both energy demand and emissions have been steadily increasing through the 2010s.

Many studies have modelled diverse scenarios evaluating the present and projecting future energy requirements and emissions of India's transport sector. This paper analyses three primary models to understand the current scenario and recommend future pathways to energy transition.

The three models being considered are:

i. the Carbon Transparency Initiative (CTI) Model

ii. the TERI Transport and TERI Market Allocation (TMA) Model

iii. the Global Energy and Climate's GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) Model

The CTI model, called "Decarbonising the Indian Transport Sector: Pathways and Policies", was spelt out in a 2020 report prepared by two global non-profits which conducts research on climate science and policy, the New Climate Institute and Climate Analytics.[34] The TMA model was part of a 2021 report, "Decarbonisation of the Transport Sector in India: Present Status and Future Pathways", prepared by the New Delhi think tank, The Energy and Research Institute (TERI).[35] The GEC model was included in the 2022 IEA-Niti Aayog report mentioned earlier, "Transitioning India's Road Transport Sector: Achieving Climate and Air Quality Advantages".[36]

Current Realities and Future Projections

The Carbon Transparency Initiative (CTI) Model

The CTI model provides a framework to assess various decarbonisation strategies within the transport sector up to 2050.[37] It delineates three distinct decarbonisation scenarios:

a. Business-as-usual (BAU)

b. a rail-focused scenario anticipating a substantial transition from road-based to rail-based transportation in the freight sector, as well as from private to public transportation in the passenger sector

c. a road-focused scenario, where both passenger and freight transportation are prioritised at a modal electrification rate consistent with the projected development

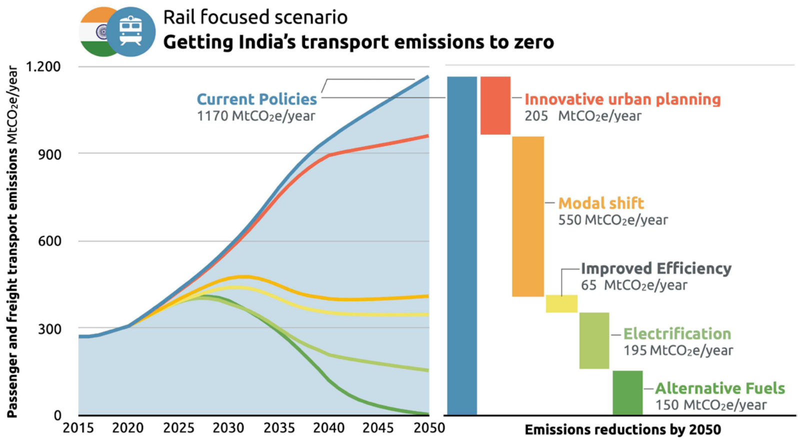
It also evaluates the prospective decrease in annual emissions by the transport sector, focusing on five primary policy interventions:

- Innovative Urban Planning
- Modal Shift
- Efficiency Enhancement
- Electrification
- Adoption of Alternative Fuels

It then projects the aggregate energy demand for transportation, categorised by fuel type, for rail- and road-based scenarios.

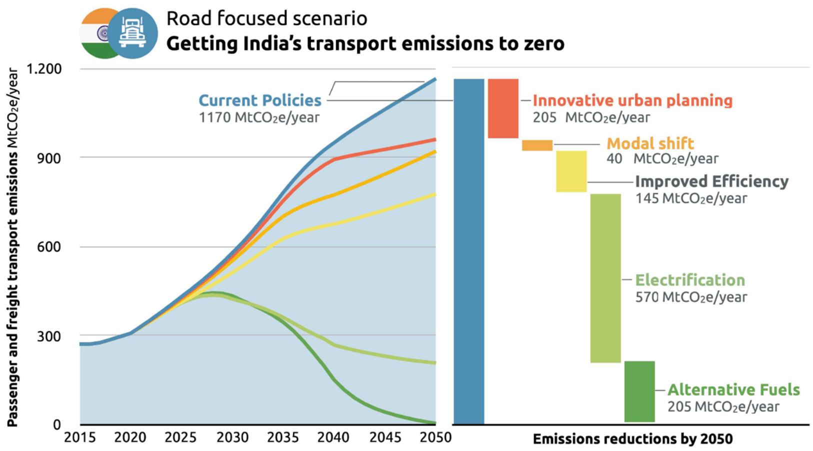
Figures 2 and 3 illustrate the aggregate passenger and freight transport emissions across all the three scenarios and how the suggested policies aimed at attaining zero-emission by India's transport sector would influence them.

Figure 3: Annual Emissions From the Transport Sector – 'Rail-Focused Scenario' ($MtCO_2/e$) – CTI Model



Source: Decarbonising the Indian Transport Sector: Pathways and Policies.[38]

Figure 4: Annual Emissions From the Transport Sector – 'Road-Focused Scenario' ($MtCO_2/e$) – CTI Model



Source: Decarbonising the Indian Transport Sector: Pathways and Policies.[39]

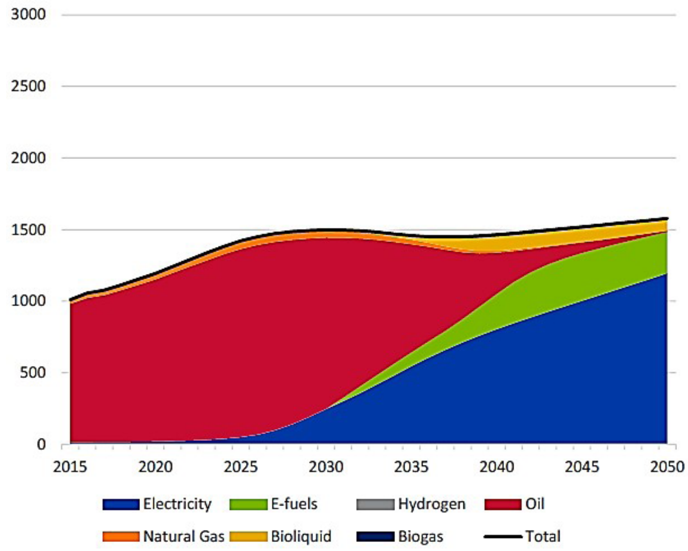
The figures demonstrate that innovative urban planning can make a difference, whether in the road-based scenario or rail-based. Integrating transit-oriented development (ToD) into urban planning holds immense promise.

The rail-centric scenario suggested policy interventions such as setting up integrated multimodal transport systems within urban areas, implementing low-emission zones within central business districts (CBDs), enhancing pedestrian and cyclist infrastructure, and introducing innovative funding mechanisms for public transport.

The road-centric scenario focuses on mitigation, notably improving fuel efficiency standards and adopting large scale electrification and low-carbon fuels, through incentives to buy EVs providing extensive and accessible charging infrastructure, and limiting the sale and registration of ICE vehicles.

Figures 5 and 6 illustrate the projected trajectories of transport energy demand (in terawatt hours (TWh)) for various fuel types under both rail-focused and road-focused scenarios by 2050.

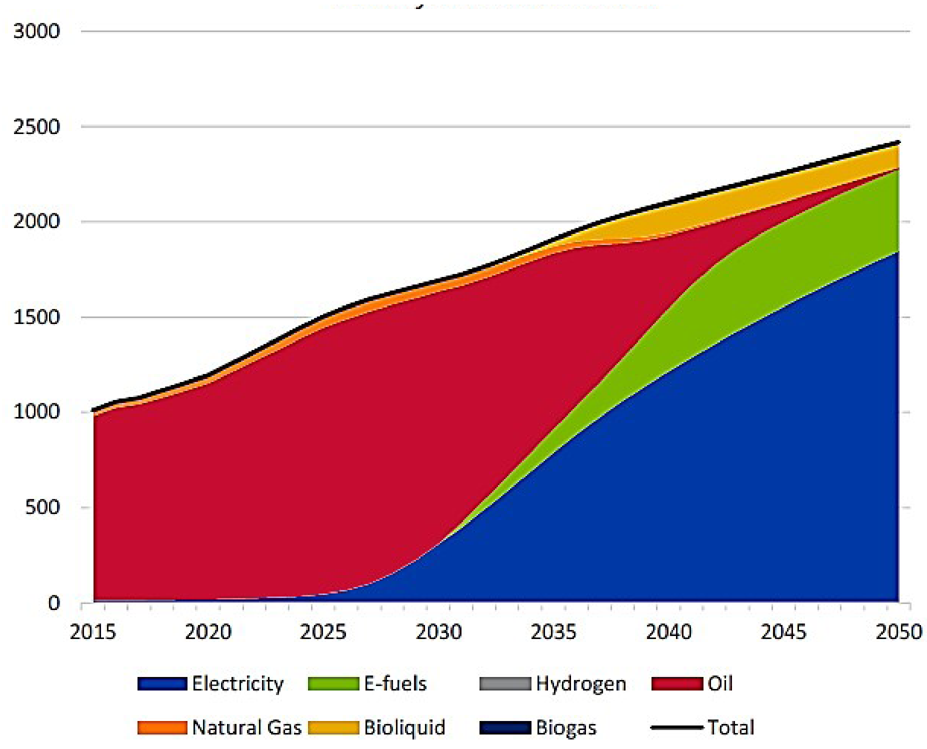
Figure 5: Total Energy Demand by Fuel Type in 'Rail-Focused Scenario' – CTI Model



Source: Decarbonising the Indian Transport Sector: Pathways and Policies.[40]

The graphs suggest that oil, the primary fuel source of the transport sector at present, will gradually give way to electricity by 2050. However, they suggest that other clean energy sources are also essential to achieve net-zero in transportation emissions by that year. (No doubt the trajectory delineated may change if technological advances produce still cleaner energy sources in the coming years.)

Figure 6: Total Energy Demand by Fuel Type in 'Road-Focused Scenario' – CTI Model



Source: Decarbonising the Indian Transport Sector: Pathways and Policies.[41]

The TERI Transport and Market Allocation (TMA) Model

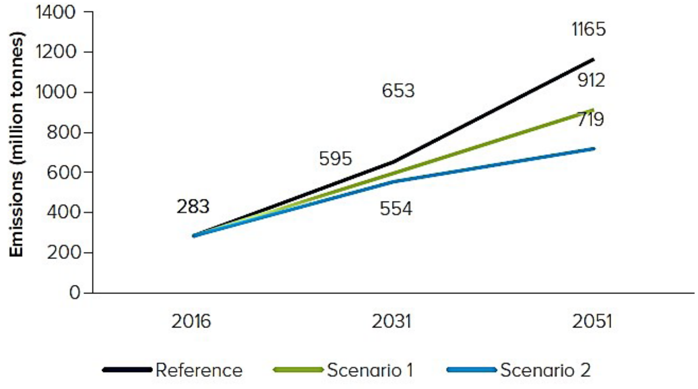
The Transport Market Allocation (TMA) model presents a separate approach to estimating decarbonisation and energy transition trajectories of the transport sector till 2050.[42] Like the CTI model, it formulates three scenarios:

- BAU (here called the 'reference' scenario)
- the 'electrification of 'easier-to-transition' segments scenario (Scenario 1)'
- the above electrification combined with solutions for 'hard-to-abate' segments (Scenario 2)

Each of these considered the adoption rates of various fuel types across passenger and freight transport vehicle segments—petrol, diesel, compressed natural gas (CNG), liquefied natural gas (LNG), EVs, and fuel cells.

Figure 7 shows the aggregate CO_2 emissions in each of the three scenarios.

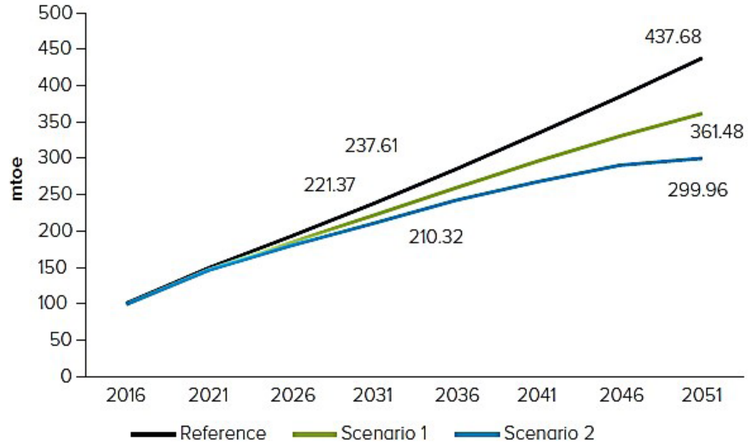
Figure 7: CO_2 Emissions From the Transport Sectors, by Scenario – TMA Model



Source: Decarbonisation of Transport Sector In India: Present Status and Future Pathways.[43]

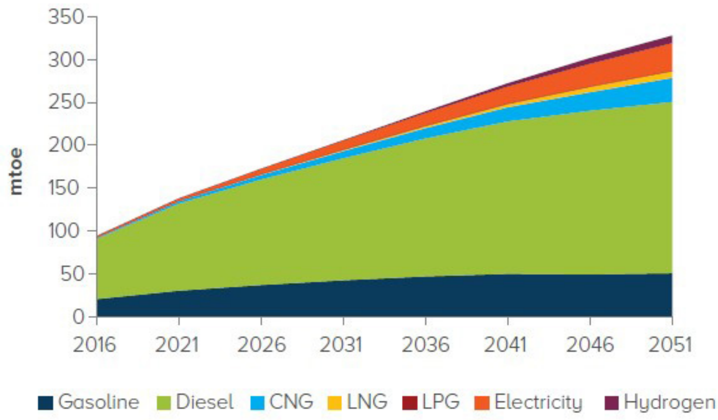
The BAU model projects cumulative emissions of 1,165 million tonnes by 2050. However, the modelling shows that implementing the alternative Scenarios 1 and 2 can mitigate India's emissions by 22 percent and 39 percent, respectively. But such mitigation can only be achieved through bold EV policies, nurturing innovation in low-carbon technologies for long-distance heavy-duty vehicles (HDVs), enhancing logistics efficiency, augmenting public transport services, making a modal shift towards railways, arresting the proliferation of motorisation, and addressing the inconsistencies and inequalities inherent in extant policies. Figure 8 shows the total energy requirement for all three scenarios, while Figures 9 and 10 illustrate the energy requirement by fuel type for both Scenarios 1 and 2.

Figure 8: Energy From the Transport Sectors, by Scenario – TMA Model



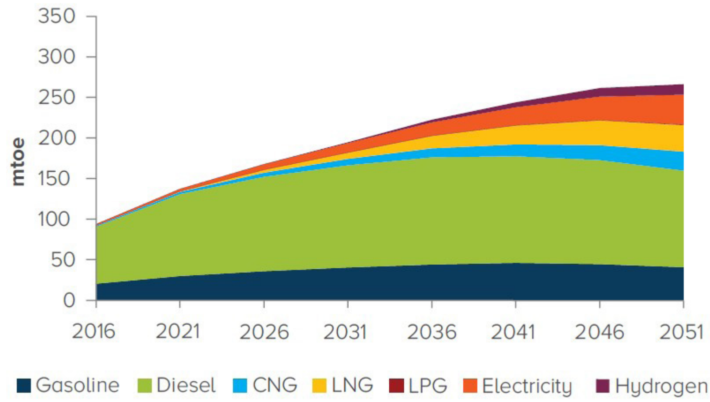
Source: Decarbonisation of Transport Sector In India: Present Status and Future Pathways.[44]

Figure 9: Energy Requirement, by Fuel Type in Scenario 1 – TMA Model



Source: Decarbonisation of Transport Sector In India: Present Status and Future Pathways.[45]

Figure 10: Energy Requirement by Fuel Type in Scenario 2 – TMA Model



Source: Decarbonisation of Transport Sector In India: Present Status and Future Pathways[46]

In the BAU (reference) scenario, diesel remains the predominant fuel source, constituting approximately 55 percent of the demand by 2050, despite a gradual reduction from 2041. Scenario 1 envisages a reduction, with diesel accounting for 40 percent of the total energy demand; it expects diesel demand to peak around 2040, and thereafter gradually decline with increased use of electrified rail for freight movement and wider adoption of low-emission technologies by HDVs. The findings underscore the importance of transitioning freight movement to low-carbon modes, especially over long distances. Scenario 1 shows that a high level of electrification alone could reduce emissions up to 9 percent by 2030 and 22 percent by 2050.

Implementing decarbonisation strategies which include the 'hard-to-abate' segments could achieve reductions of 15 percent by 2030 and 38 percent by 2050. Even so, the transportation sector's emission contribution to total emissions in 2050 will remain around 15 percent in the first scenario and 12 percent in the second.

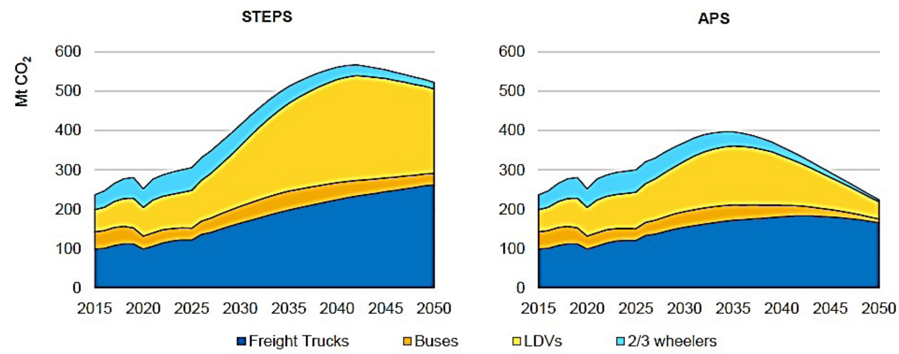
Global Energy and Climate Model

The IEA's GEC (GAINS) model visualises two scenarios:

- the Stated Policies Scenario (STEPS)
- the Announced Pledges Scenario (APS)

Figure 11 shows emissions by different vehicle categories in both scenarios.

Figure 11: CO_2 Emissions by Vehicle Category in the STEPS and APS Scenario – GEC Model



Source: Transitioning India's Road Transport Sector Realising climate and air quality benefits.[47]

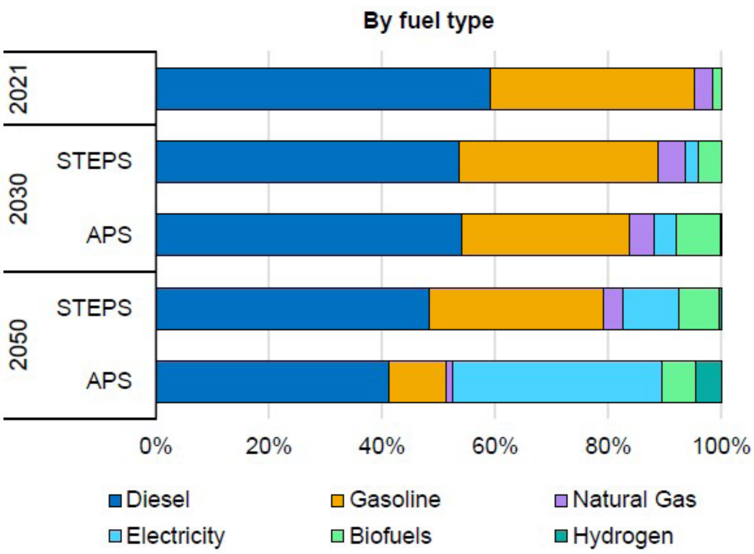
If current policies continue, and the road transport industry keeps expanding the way it is doing, the STEPS model shows that not only will road transport emissions increase by 2050, but the sector's share in overall emissions will also rise, particularly if the power sector—the biggest polluter at present—adopts renewable energy in a major way. The STEPS scenario predicts doubling of emissions by the road transport sector by 2040, reaching 560 million metric tonnes, with a minor decline thereafter.

If the pledges India has made at various COP conferences are honoured, the APS scenario shows that emissions will peak by the mid-2030s and then begin to decline, falling to less than 230 million metric tonnes by 2050 (about the same as at present). If the ambitious transition strategy outlined in the APS scenario is pursued, the transport sector will have emitted 4 Gigatons less of CO_2 between 2022 and 2050 than if current policies continue. One-third of the additional emission reductions by 2030 could come from ICE vehicles implementing enhanced energy efficiency measures, accelerated EV adoption, and increased use of bio-fuels.

No doubt EVs are not a foolproof panacea; their use also has emission consequences. Unlike ICE vehicles, EVs do not have tailpipe emissions, but their use leads to increased electricity demand, and generating the additional power results in higher power plant-level emissions. Given India's heavy reliance on fossil fuels, predominantly coal, EVs indirectly cause emissions too. The mitigation potential of EVs is intricately linked to the greening of India's power grid.

India must prioritise several policy interventions to attain the climate targets it has set itself. These include bolstering the framework for transport policy formulation, enhancing fuel efficiency standards for passenger cars and two-wheelers, increasing support for EVs through comprehensive total cost of ownership (TCO) assessments, fortifying EV financing mechanisms, ramping up charging infrastructure, transitioning the freight truck fleet to EVs and later, hydrogen, implementing strategies to mitigate air pollution, and intensifying international cooperation and engagement endeavours. Figure 12 shows the energy requirement for the transport sector for each fuel category.

Figure 12: Energy Requirement Based on Different Fuel Types as per STEPS and APS Models



Source: Transitioning India's Road Transport Sector: Realising Climate and Air Quality Benefits.[48]

Current Realities and Future Projections

The STEPS scenario forecasts a substantial rise in energy use from road transportation up to 2050, reaching an estimated 215 million tonnes of oil equivalent (Mtoe). The APS scenario predicts a decline in energy demand by 30 percent, resulting in total energy consumption of less than 145 Mtoe by 2050. If it adheres to the APS trajectory, India would, by 2050, have saved nearly 80 percent of the current energy consumption of its transportation sector. But this can only be possible by large-scale transitioning to EVs, with energy efficiency levels two to four times higher than comparable ICE vehicles, and efficiency improvements of ICE vehicles as well.

The STEPS scenario anticipates petrol and diesel to still fulfil roughly 80 percent of fuel demand in 2050 (down from 95 percent at present), with electricity contributing 10 percent, and bio-fuels and CNG the remainder. The APS projects trucks and buses to draw half the petrol and diesel consumption by 2050. It expects higher penetration of EVs in the overall vehicle population to meet nearly 40 percent of the sector's mid-century energy needs, given their superior energy efficiency.

The APS scenario also predicts an upsurge in the use of bio-fuels until 2030, albeit with insignificant growth thereafter. By 2050, both STEPS and APS expect bio-fuels to cater to 6-7 percent of road transport energy demand. While both scenarios predict an uptick in CNG consumption until 2030, STEPS anticipates its continued rise thereafter against a decline predicted by APS. STEPS maintains that bio-fuels and natural gas will predominantly cater to passenger cars by 2050, while the APS model expects their use restricted to heavy trucks and buses, anticipating widespread electrification of cars by that time. APS anticipates hydrogen to emerge as an alternative fuel for cars and heavy-duty freight trucks in 2040, satisfying 5 percent of the road transport sector's energy demand by 2050, six times more than the STEPS scenario does.

Table 2 summaries the key insights from the three models studied above.

Table 2: Decarbonisation and Energy Transition Models for India's Transport Sector

Model Name	Horizon year	Scenarios presented	Alternative fuel considered	Total CO_2 Emission by horizon year (Million tonnes)	Total energy requirement (Million tonnes of oil equivalent)
Carbon Transparency Initiative (CTI model)	2050	1. Business as Usual (BAU) 2. Rail-focused Scenario 3. Road-focused Scenario	Electricity, Hydrogen, Oil, Natural Gas, Bio -liquid, and Biogas	As per the BAU scenario: **1170**	Rail-focused scenario: **129** Road-focused scenario: **207**
TERI Transport Market Allocation (TMA model)	2051	1. Business as Usual (BAU) 2. Electrification for easier-to-transition segments (Scenario 1) 3. Electrification combined with solutions for hard-to-abate segments (Scenario 2)	Gasoline, Diesel, CNG, LNG, LPG, Electricity, Hydrogen	BAU scenario: **1165** Scenario 1: **912** Scenario 2: **719**	BAU scenario: **438** Scenario 1: **362** Scenario 2: **300**
IEA's Global Energy and Climate (GEC model)	2050	1. Stated Policies Scenario (STEPS) 2. Announced Pledges Scenario (APS)	Diesel, Electricity, Gasoline, Bio-fuels, Natural gas, Hydrogen	STEP: **560** APS: **224**	STEP:**215** APS:**145**

Source: Author's own

A Comparison of the Three Models

Each of the models discussed above employs a different approach to project future emissions and energy requirements. These will now be compared from the perspective of modelling approaches, underlying assumptions, and total emission and energy requirement estimates.

Modelling Approaches

The CTI model is a bottom-up modelling tool focused on estimating energy demand and emissions at a granular level. It analyses activity levels within both the passenger and freight transport segments, factoring in population growth and GDP forecasts. It provides a detailed disaggregation of emissions sources, with insights into energy consumption across different transport modes. Its strength lies in its targeted insights based on specific activity levels, making it particularly useful in estimating transport sector emissions in detail.

The TMA model estimates demand in both the passenger and freight segments over time. It projects emissions and energy consumption. It is a general equilibrium model that simulates the entire energy system, enabling it to provide a more comprehensive view of the interactions between energy demand and emissions across all sectors. This system-wide perspective makes it suitable for understanding the broader implications of de-carbonising the transport sector.

The IEA's GAINS model, developed with the International Institute for Applied Systems Analysis (IIASA), differs from both the CTI and TMA models by focusing not only on emissions but also on the impacts of policy actions on air quality. This top-down approach simulates two scenarios to project the benefits of transitioning to cleaner transport systems. It is particularly effective in estimating how improvements in energy efficiency and the adoption of cleaner technologies, such as EVs, can reduce both emissions and air pollutants. The GAINS model offers a robust analysis of policy impacts on both climate and air quality.

A Comparison of the Three Models

Each model brings unique strengths to the table: the CTI model provides segment-specific insights; TERI models the entire energy system, while the GAINS model emphasises co-benefits related to air quality improvement alongside emission reductions. Together, they provide complementary views of decarbonisation and energy transition.

Assumptions

The CTI model proposes three alternative scenarios: BAU, rail-focused transition and road-focused transition. The second alternative envisages a significant shift from private to public transport in the passenger sector and road-based to rail-based logistics in the freight sector. It expects rail services for passengers to be expanded too, displacing private vehicle usage—a host of Indian cities are indeed building or expanding metro systems. Bus services are also growing and the demand for private vehicles declining. Modernising and improving the railway system as a whole—and not just in urban areas—can reverse the current downward trend in rail-based freight, and lead to a significant increase in rail's share of long-haul freight transportation.

The road-focused transition emphasises road transport, expecting continued expansion of private passenger vehicles and road-based freight transport in line with projected growth patterns. It estimates an increased demand for road infrastructure from both passengers and freight, while rail freight transportation retains its current share of the modal distribution.

The TERI BAU model assumes a gradual transitioning to EVs, a focus on sectors that are more amenable to mitigation, while predicting limited adoption in the 'hard-to-abate' ones. It envisions minimal changes in technology integration or shifts in transportation modes. Railway electrification is projected to progress at a slow pace, with full track electrification only by 2035. Overall, it predicts that under this scenario, the share of rail in freight transportation will fall from 26 percent in 2015 to 20 percent by 2050, while its passenger share will also drop from 14 percent to 10 percent over the same period.

A Comparison of the Three Models

The second scenario focuses on widespread adoption of EVs, with the necessary infrastructure also in place, anticipating its significant penetration across various vehicle categories. However, it acknowledges a continued dependency on diesel and a relatively stable role for rail transport in both the passenger and freight sectors. It envisions a swifter uptake of EVs in segments more conducive to transition, while the decarbonisation strategies of the others remain underdeveloped. The adoption of EVs is projected to be higher in segments with easier transitions, such as two-wheelers and three-wheelers (where around 70 percent of vehicles are expected to be electric by 2050); personal vehicles and taxis (where the penetration would be around 50 percent by then), driven by advances in battery technology and availability of more affordable vehicle models; and LCVs (where it would be around 60 percent). However, it expects electrification of intercity buses and medium- and heavy-duty commercial vehicles (M/HCVs) to remain limited (where it would be around 5 percent). Overall adoption of EVs is projected to accelerate significantly after 2030, though rural areas are expected to have low EV and compressed natural gas (CNG) adoption rates until 2040, with growth accelerating thereafter. As a result, it maintains gasoline-based fuels will continue to power some vehicles in these segments even in 2050.

TERI's third scenario imagines difficult-to-decarbonise road transport segments, such as intercity buses and HDVs, also being tackled alongside the easier ones. It assumes swift adoption of fuel cell vehicles and liquefied natural gas (LNG) technology by medium duty vehicles (MDVs) and HDVs, with electrification also being considered for certain MDVs. It projects that by 2050 nearly 40 percent of intercity buses (MDVs) will operate on hydrogen or LNG, as also that LNG and hydrogen-powered trucks will comprise 40 percent of all heavy trucks. It also envisages a more rapid modal shift from road to rail for freight transportation, with rail capturing 45 percent of freight movement by 2040 and 50 percent by 2050. It anticipates a faster uptake of electric vehicles, fuel cell vehicles, and LNG technologies across truck and intercity bus fleets.

The IEA's STEPS model assumes India will achieve 450 GW of renewable energy by 2030, which will comprise at least 50 percent of its total installed capacity. It also expects full implementation of the second phase of the Faster

A Comparison of the Three Models

Adoption and Manufacturing of Electric Vehicles (FAME II) programme, the adoption of state-level EV policies, and partial rollout of an amended bio-fuel policy (initially announced in 2022). It envisages fuel economy standards for passenger vehicles set at 113 g CO_2 per km, along with fuel economy targets for HDVs, enforcement of Bharat Stage VI emissions standards for both light-duty vehicles (LDVs) and HDVs, and increased investments in urban infrastructure and public transportation systems.

IEA's second scenario, the Alternative Policy Scenario (APS), assumes successful and timely realisation of all energy and climate pledges made by India, including its long-term commitments to achieving net-zero emissions. Specifically, it envisions India adopting a pathway to net-zero emissions by 2070. It expects the midway goal of 45 percent reduction in the economy's emissions' intensity by 2030 relative to 2005 levels, as outlined in India's updated Nationally Determined Contributions (NDC), to be met. It anticipates India reaching 500 GW of non-fossil energy capacity by 2030 and a reduction of 1 Gigaton of CO_2 emissions by 2030, as Prime Minister Narendra Modi promised at the Glasgow COP26 in 2021. It accepts the claim that the FAME II scheme will facilitate sales of 500,000 electric three-wheelers and 1 million electric two-wheelers; it believes Indian Railways will meet its net-zero goal set for 2030.

CO_2 Emissions and Energy Requirements

It can be seen that there are significant variations in the projections of these models. The estimate of total CO_2 emissions, for instance, varies from a minimum of 224 million tonnes in the GEC model's APS scenario to a maximum of 912 million tonnes in the TMA model's Scenario 2.

A detailed analysis of energy requirements yields similar disparities. The total energy requirement, measured in Mtoe, was the least at 129 million tonnes in the CTI model's rail-focused scenario, while the maximum was 362 million tonnes in Scenario 1 of the TMA model. These substantial differences in predictions stem from varying assumptions and forecasts of the input variables influencing decarbonisation and energy transition.

Inferences

The above findings highlight the need for cautious interpretation of the absolute values presented in these projections. Their predictions are dependent on assumptions made for their input variables, a slight change in which can significantly change the CO_2 emissions and energy requirement demand estimates. Policymakers and practitioners must therefore understand the underlying factors that influence decarbonisation and energy transition pathways rather than concentrating solely on the numerical predictions.

An analysis of the three models also reveals that variables such as the annual average annual GDP and population growth, and growth in passenger kilometres travelled, ownership rates of two-wheelers, three-wheelers, and cars, future demand for freight vehicles, technology share of new vehicles, modal share of private and public transport, and vehicle utilisation rates, are all critical factors influencing energy transition pathways in India's transport sector.

The overall inference that can be derived is that future government schemes, policies, missions, and plans must be meticulously designed, carefully considering their impact on the critical factors influencing decarbonisation. They must be strategically aligned to maximise their impact on emissions. An integrated approach, encompassing technological, economic, and societal factors, will ensure that each component of the strategy contributes meaningfully to the overall objective of sustainability and climate resilience.

Barriers to Decarbonisation

A comprehensive assessment of the current landscape reveals myriad challenges in India's quest towards net-zero transport sector emissions. They include:

Social Impact Barriers

Coal India Limited, a public-sector undertaking, produces the bulk of the approximately 730 million tonnes of coal mined in India every year, with coal mining contributing up to 2.5 percent to the national GDP.[49] Coal mines employ about 355,000 workers out of India's total workforce of nearly 450 million.[50] The sector's allied segments, not including logistics and road and rail transportation, offers livelihood opportunities to an additional 1.2 million people.[51] The move to cleaner energy sources is already leading to job losses and decreased state revenue from coal, impacting social and infrastructure facilities in specific areas, highlighting the criticality of 'just transition'. A just transition framework must aim to not only formalise the coal sector but also achieve the essential 'Energy Democracy' characteristics.

Problems with Alternative Fuels

Ethanol, a liquid bio-fuel produced from cereals and sugar as feedstock, is gaining global attention as an alternative to fossil fuels. However, there are problems with feedstock availability, while establishing new production capacities call for high capital investments,[52] which may impede ethanol supply in the required quantities. Last year, for instance, realising sugar production would fall, the Centre temporarily suspended ethanol production from sugarcane juice to prioritise domestic sugar availability. Fear of sugar falling short if too much sugarcane is diverted for ethanol makes setting a price for sugarcane-based ethanol each year challenging.[53] Availability of feedstock can also be affected by the same uncertainties from which Indian agriculture suffers, such as climate shocks and adverse weather conditions.

While ethanol production was earlier dependent entirely on sugarcane juice and syrup, the government has since permitted rice and maize to be used as feedstock too. The diversification will reduce ethanol's dependence on sugarcane, decreasing its contribution to bio-fuel production from 62 percent to approximately 50 percent by 2025-26. Higher ethanol production will also require an expeditious regulatory clearance mechanism, improved transportation and storage infrastructure.

With biodiesel too—made by chemically treating various seed crops, vegetable oils and animal fat with alcohol—there are impediments. Farmers are reluctant to grow non-edible seeds crops for lack of state incentives, as are oil companies to even procure large quantities of biodiesel.[54,55] Methanol is yet another alternative fuel, but it has yet to find a market in India, barring a few pilot projects. Moreover, petrol-powered vehicles will need material modifications and recalibration if they are to use methanol.[56] Its economic viability depends on production costs, which in turn depend on the cost of essential inputs, mainly green hydrogen.[57]

There are problems with large-scale use of electric batteries and hydrogen too, including their technical capabilities and maturity, the driving range limitations they impose, the time taken to recharge them and the lack of widespread charging infrastructure, the emissions arising from the power plants which provide their charge, the higher initial cost of such vehicles, concerns around operating and maintenance costs, safety concerns, and whimsical government support.[58]

Infrastructural and Financial Barriers

The IEA model estimated investments of USD 210 million in 2016-2020 to US$19-33 billion in 2026-2030 for India to achieve its net-zero targets.[59] Securing investments on such a scale, while maintaining fiscal prudence, will be difficult. The government will have to consider end-user expenses, which are bound to rise in the initial years of adoption, as technologies such as green hydrogen and even battery storage, remain relatively costly.[60]

Land acquisition is another barrier, especially for the vast areas that solar plants need.[d] Unclear land records and titles, inflated land prices in regions with high solar potential, and conflicts with local communities culminating in long-drawn litigation, can lead to project cost and time overruns.[61]

Institutional, Policy and Regulatory Barriers

In a number of countries, the absence of well-defined administrative and legal frameworks has been hindering coordinated policy efforts essential for energy transition.[62] In the United States, for example, the National Environmental Policy Act (NEPA), enacted in the 1970s to ensure

d Producing a single megawatt of solar power requires setting up solar modules across 4-5 acres of land, or about 6,000 square meters.

due diligence of environmental impacts of projects by developers, has paradoxically allowed affluent stakeholders to utilise litigation as a powerful tool to hinder progress[63]—what was intended as a protective measure against environmental degradation has become a barrier to developing clean energy infrastructure. Numerous state and local regulations further exacerbate these challenges in the US, such as moratoriums on nuclear energy, halts on planned CO_2 conveyance pipelines, and restrictions on mining.[64]

Similarly, despite being at the forefront of renewable energy advancements with its *Energiewende* (energy transition) initiative, Germany has faced considerable challenges. *Energiewende* calls for collaboration of various federal ministries and state governments, which often leads to delays and inconsistencies in policy execution, while the country's legal framework struggles to keep pace with rapid technological and market changes. The country's Renewable Energy Sources Act (EEG) has undergone numerous revisions, creating uncertainty for investors and developers.[65]

Conflicting institutional interests present a major obstacle for emission reduction everywhere. In India, the coal ministry, for example, might resist measures aimed at reducing coal consumption or mandating advanced clean coal technologies, as these actions could negatively impact the coal sector and government revenues from it.[66] Though policymakers have increasingly focused on energy transition and climate change in the last two decades, the lack of an appropriate institutional framework continues to remain a challenge.

Policy Implications and Recommendations

A number of transport strategies can help in achieving India's net-zero target. Table 3 captures the most prominent policy interventions highlighted in all the three reports.

Table 3: Policy Implications Highlighted in Different Models

Policies	CTI model	TMA model	GEC model
Develop sustainable metropolitan areas	✓	×	×
Reduce passenger cars and freight trucks use in cities	✓	✓	×
Integrate transport services to encourage use of public and shared services	✓	✓	×
Improve walking and cycling infrastructure	✓	✓	×
Fund and develop affordable public transport	✓	✓	×
Build sustainable long-term infrastructure aligned with climate targets and the Paris agreement	✓	✓	×
Develop and support railway infrastructure and services	✓	✓	×
Establish a level playing field and tax air travel to limit its growth	✓	×	×
Provide financial support for EV uptake	✓	✓	✓
Take necessary supply-side measures for EV uptake	✓	✓	×
Provide behavioural incentives for zero emission vehicles	✓	×	×
Improve EV charging infrastructure	✓	✓	✓

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Policies	CTI model	TMA model	GEC model
Improve logistics sector efficiencies	×	✓	✓
Overcome overarching policy issues	×	✓	✓
Control motorisation growth rate	×	✓	×
Strengthen fuel economy standards	×	✓	✓
Strengthen emissions standards	×	×	✓
Accelerate fleet renewal	×	×	✓
Enhance international collaboration and engagement efforts	×	✓	×

Source: Author's own

Recommendations

Although categorised under specific policy interventions, the three models all emphasise the critical measures necessary to facilitate a seamless energy transition in the transport sector. Effectively implementing the recommendations will require a host of supportive steps: proactive government action to foster enhanced stakeholder collaboration, robust and efficient institutional frameworks and regulatory measures to streamline fuel economy standards, comprehensive mechanisms to finance India's green transition in transportation, support for non-motorised transport (NMT) (such as bicycles) and public transport infrastructure, a focus on road logistics, and standardised frameworks for data availability and modelling.

Policy Implications and Recommendations

Enhance Stakeholder Collaboration

The transportation sector involves diverse stakeholders, of whom the most important ones can be broadly grouped under three heads – 'energy,' 'transport,' and 'transition' – who together facilitate investments, operations, utilisation, governance, and energy resources for energy transition.[67] Energy actors include producer associations, producers, grid operators, ministries, and coal mining companies. Transport actors encompass EV manufacturers, associations, city planners, freight distributors, transport ministries, fuel distributors, and public transport and mobility service providers. Transition actors comprise financial institutions, investors, central, state and city governments, customers, and developmental organisations. Since all these actors need to consult and collaborate to develop financially viable solutions for effective energy transition for the transport sector, the government will need to set up consultative platforms for them.

Other stakeholders include non-state actors, especially the financial sector, academia, labour unions, environmental organisations, and civil society – they would all need to be consulted too before crucial integrated solutions can be decided upon. Governments must create a supportive environment by establishing dedicated cross-sectoral roles and departments to oversee and support these processes.[68] India could learn from global collaborative initiatives such as the United Nations' Sustainable Energy for All, the IEA's Clean Energy Transitions Programme, the Energy Transitions Commission, and the Leadership Group for Industry Transition, which have successfully leveraged diverse expertise for power and industry sector transitions.[69]

Establish Institutional Frameworks

Various government bodies are implementing diverse strategies to decarbonise India's transport sector. To streamline and consolidate these efforts, it is essential that both the Centre and the states adopt the institutional framework for transport planning, as recommended in the National Transport Development Policy Committee Report, 2014.[70] Inter-ministerial climate or sustainability councils should be set up which can enhance collaboration. The Prime Minister's Council on Climate Change has already prepared a National Action Plan on Climate Change (NAPCC) which outlines an institutional framework, consisting of a core negotiating team, a coordination unit for implementation, and also involving research institutes and the Ministry of Science and Technology. But how effective has it been so far is an open question.[71]

Table 4: Ministries Involved in Transport Sector Decarbonisation

Ministry	Roles	Responsibilities	Recent initiatives
Ministry of Road Transport and Highways (MoRTH)	Primarily responsible for developing policies related to road transport and infrastructure.	Sets vehicle registration policies, scrapping schemes, and fuel-efficiency standards. Also oversees development of EV charging infrastructure on highways.	• Green Highways Policy[72] • Scrappage Policy[73]
Ministry of Power (MoP)	Develops the necessary energy infrastructure for decarbonisation by expanding the availability of EV charging stations and ensuring the integration of renewable energy into the national grid.	Issues guidelines and standards for EV charging stations and ensures power supply from renewable sources to reduce transport emissions.	• Guidelines for Charging Infrastructure for EVs[74] • National Tariff Policy Amendments[75]

Ministry	Roles	Responsibilities	Recent initiatives
Ministry of Heavy Industries (MHI)	Promotes the manufacturing and adoption of EVs and hydrogen fuel cell technologies.	Works with the automotive industry to incentivise the production and adoption of EVs and hydrogen-powered vehicles.	• Production-Linked Incentive (PLI) Scheme for Automotive Sector[76] • Faster Adoption and Manufacturing of Electric Vehicles (FAME) II[77] • National Electric Mobility Mission Plan (NEMMP)[78]
Ministry of New and Renewable Energy (MNRE)	Promotes the use of renewable energy in transportation.	Develops policies for integrating renewable energy with transport, including using solar energy for charging infrastructure and hydrogen as an alternative fuel for long-haul movement.	• National Green Hydrogen Mission[79] • Promotion of Solar-Powered Vehicles • Biomass in Transport Fuels
Ministry of Petroleum and Natural Gas (MoPNG)	Promote bio-fuels and alternative fuels like compressed biogas (CBG) under initiatives such as the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme.	Encourages the use of bio-fuels, reducing dependence on traditional fossil fuels. Also promotes CBG as a cleaner alternative for heavy-duty transport.	• Sustainable Alternative Towards Affordable Transportation (SATAT)[80] • Ethanol Blending Programme[81] • Green Hydrogen and LNG Promotion

Ministry	Roles	Responsibilities	Recent initiatives
Ministry of Environment, Forests, and Climate Change (MoEFCC)	Sets emission standards and enforcing the NAPCC.	Monitors and regulates emissions and coordinates national policies to align with India's climate commitments.	• National Action Plan on Climate Change (NAPCC)[82] • Promotion of Sustainable Urban Transport
Ministry of Housing and Urban Affairs (MoHUA)	Focuses on urban mobility, promoting public transit, and non-motorised transport.	Develops policies for sustainable urban transport systems like electric buses, metro rail, and cycling infrastructure to reduce the carbon footprint of cities.	• Smart Cities Mission[83] • Urban Transport Fund[84] • National TOD Policy[85]

Source: Author's own

Establish an Overarching Transport Decarbonisation Authority

The absence of a unified institutional framework has impeded effective decarbonisation. Overlapping responsibilities among ministries have led to policy conflicts. Each ministry's priorities are different; they support different low-carbon technologies, leading to misalignment in long-term decarbonisation goals. Funding mechanisms across ministries also work in silos leading to duplication of efforts and hindering large-scale collaboration. Regulatory and technical barriers also arise from different ministries setting their own standards, leading to inconsistencies in technology and infrastructure deployment. Weak coordination between central and state governments or urban local bodies further delays adoption of low-carbon transport systems.

Policy Implications and Recommendations

Policy interventions are needed to address these shortcomings. First, a centralised authority, which could be called the National Transport Decarbonisation Authority, should be set up and should oversee all decarbonisation efforts, aligning them within a single framework. It should function as a multi-stakeholder entity, integrating expertise from government, industry, academia, urban planners and civil society to design and implement holistic strategies for transport de-carbonisation. To ensure robust technical and policy guidance, academia should include institutions like the Indian Institutes of Technology (IITs) and the National Institutes of Technology (NITs); civil society groups should encompass the Observer Research Foundation, Clean Air Asia and The Energy and Resources Institute (TERI). Even international organisations like the International Energy Agency (IEA) and the World Resources Institute (WRI) could provide valuable global insights.

Members should possess comprehensive skill sets to effectively fulfil the NTDA's mandate. Key areas of expertise should include decarbonisation strategies, integration of renewable energy, transport policy formulation, sustainable finance mechanisms, urban planning, behavioural sciences, stakeholder collaboration, data analytics, and transport network modelling. This diverse knowledge base would enable the NTDA to develop and implement strategies that align with India's climate goals while addressing the unique needs of the transport sector.

Such a strategy would establish clear and time-bound targets for emission reductions across all relevant ministries. Obviously, robust monitoring frameworks will be required as well to ensure accountability. Monitoring, Reporting, and Verification (MRV) systems should be set up incorporating tools such as annual carbon budgets to allocate emission caps across sectors and independent third-party audits to verify reported data and evaluate progress. Performance-based evaluations leveraging Key Performance Indicators (KPIs) would enable systematic assessment of ministries and sectors based on predefined emission reduction goals. There should be international benchmarking and compliance mechanisms, such as alignment with India's Nationally Determined Contributions (NDCs) under the United Nations Framework Convention on Climate Change (UNFCCC), which would provide global comparability and encourage adherence to international climate commitments. As for funding, cross-ministerial funding instruments would streamline resource allocation, enabling ministries to collaborate on large-scale projects such as EV infrastructure development and hydrogen fuel stations.

Developing unified technical standards across ministries for EVs, charging infrastructure, and alternative fuels will reduce inconsistencies and promote faster adoption of low-carbon technologies. The government need not own any assets but should be an enabler for creation of the EV infrastructure; it should establish inter-ministerial task forces for specific projects and encourage public-private-partnerships (PPPs). Existing technical capacity within government agencies should be augmented through targeted capacity-building programmes, or by setting up dedicated entities for transport planning such as Delhi has done with its Delhi Integrated Multimodal Transit System (DIMTS).

Explore Unconventional Means of Financing India's Green Transport Transition

Petroleum taxation has been a substantial contributor to India's GDP, consistently exceeding 2 percent over the past decade.[86] An analysis of tax data from 2010 to 2017 indicates that India derived 45 percent of central government taxes, including customs and excise duties, from the petroleum sector. Further, around 26 percent of state-level taxes, primarily sales tax, originate from this sector.[87] A significant decrease in the consumption of petroleum fuels could have profound revenue implications. It is thus essential to diversify revenue streams and proactively address potential fiscal deficits to maintain continued investment in decarbonisation infrastructure. Strategies such as congestion pricing, carbon taxation, dynamic and higher parking fees, reduced subsidies, and the introduction of user access charges for public infrastructure can partially offset the anticipated revenue losses. While these measures may recover only a portion of the lost revenue, they represent potential strategies to mitigate the fiscal impact.[88]

National-level policies and funding allocation must account for variations in urban mobility patterns and accordingly align and prioritise investments. Fiscal empowerment of city-level transportation agencies and strengthening of their technical capabilities can also help.[89]

Policy Implications and Recommendations

Infrastructure projects entail substantial investment and lengthy construction periods, further complicated by uncertainties about future revenue streams. A robust policy commitment and incorporating public financing through PPPs can mitigate risks and stimulate private investment. Indonesia's Ministry of Finance, for instance, has a PPP management unit which, by improving transparency and procedural clarity, has been able to draw a significant portion of the country's infrastructure funding needs for 2020-2024 through it.[90] It has used various public financing instruments to facilitate provision of loans, guarantees, and technical support.

Sustainable finance taxonomies, risk disclosure, and assessment processes categorise activities and assets based on their contributions to clean energy transitions or their vulnerability to financial risks associated with climate change. These guide investment decisions by delineating categories such as "green," "carbon-intensive," and "transition".[91] Notably, China has issued a Green Bond Endorsed Projects Catalogue, last updated in 2021, to guide financial institutions and corporations on issuing of green bonds.[92] Indonesia's 2022 Green Taxonomy represents one of the nation's initial policy efforts to incentivise prioritising of green investments by the private sectors.[93] India also introduced its sovereign green bonds framework in 2022, allocating funds for environmentally friendly transportation projects, among others. The inaugural green bond sale raised US$1 billion, achieving a lower borrowing cost than conventional bonds of similar maturity.[94] But India needs to develop green taxonomy further.

Promote NMT and Public Transport

A comprehensive review of urban modal share data across India reveals that 36 percent of the population still walks or cycles to work, while another 30 percent does not commute due to their proximity to their workplace. Yet another 18 percent uses public transportation, and—despite the seeming explosion of private vehicle as noted earlier in this paper—only 16 percent rely on them, with 3 percent using cars and the rest two-wheelers. Overall, around 54 percent of the population depends on non-motorised transport (NMT) for at least part of its daily commute.[95]

Policy Implications and Recommendations

Despite NMT's substantial modal share, road conditions for pedestrians and cyclists are often below par and hazardous. According to 2022 accident data from the Ministry of Road Transport and Highways (MoRTH), pedestrians were more frequently involved in fatal accidents than car occupants—that year, 32,825 pedestrians lost their lives, a 12.7 percent increase from 2021. Similarly, 4,836 cyclists died in road accidents in 2022, a 2.8 percent increase from the previous year. It shows that adequate and safe infrastructure for pedestrians and cyclists is missing, and indeed that there is a general lack of sensitivity towards them.[96]

Dedicated pedestrian walkways and cycling paths in Indian cities are few, and where they do exist, they are often poorly maintained. A qualitative assessment of NMT infrastructure, by the OMI Foundation, a policy research think tank, as part of the Ease of Moving Index 2022, revealed that in India, the average perception score of the condition of footpaths and their width as well, was a disquieting 2.8 out of 5. Safety of pedestrian crossing facilities, such as foot bridges, subways, and adequate street lighting, also stood at 2.8, while cycling infrastructure scored 3.0, and adequacy of cycle parking at transit hubs was 2.9. These findings highlight the urgent need for better infrastructure and maintenance.[97]

NMT-related urban policy goals should be pushed through incentives and competitions. States must establish dedicated NMT divisions, regularly collect and evaluate NMT usage data, create cycle lanes, enforce speed limits, designate pedestrian streets, remove obstacles to pedestrian movement, run awareness programmes, introduce congestion pricing, and implement parking taxes in congested areas.[98] The corporate sector should also facilitate remote work, incentivise NMT commuting, provide bike facilities, and offer subsidised transit passes, carpooling services, and mass transit tax benefits.[99]

Several cities worldwide have established comprehensive public transportation systems, cycling and pedestrian infrastructure and implemented innovative urban planning strategies to mitigate transport emissions. Some are transitioning to low or zero-carbon alternatives utilising contemporary solutions—Copenhagen, for instance, which aims to become carbon neutral by 2025, has over 390 km of designated bike lanes; by 2020, nearly 49 percent of its residents were using the bicycle as

Policy Implications and Recommendations

their primary and preferred mode of transport.[100] Amsterdam too has 500 km of bike lanes with 63 percent residents using the bicycle daily[101]; it has also set itself ambitious goals such as reducing car traffic by 10 percent and increasing EV and collective transport use by 80 percent by 2030.[102] Paris has complemented its extensive metro system and bus services with the Vélib' bike-sharing programme, which, when it was started in 2007, was the first of its kind in the world—it enabled cyclists to hire bicycles and drop them off at any of the numerous Velib hubs in the city instead of having to return them to where they were rented from.[103] Paris is also implementing the "15-minute city" concept to reduce car dependency and curb emissions by locating all essential services within a 15-minute walk or bike ride from homes.[104] Singapore's Land Transport Master Plan 2040 aims to ensure 75 percent of peak-hour trips by public transport while promoting active mobility options like cycling and walking.[105] All these examples provide valuable lessons for India.

Improve Regulatory Framework

Fuel economy standards are pivotal to initiatives seeking enhanced fuel efficiency of conventional vehicles. India's passenger cars industry has been meeting, and indeed surpassing, the successive Corporate Average Fuel Economy (CAFE) standards being set by the Bureau of Energy Efficiency (part of its Ministry of Environment, Forests and Climate Change). But with zero and low emission vehicles (ZELVs), adoption remains slow.[106] CAFE standards need to be made stricter and applied rigorously to all classes of vehicles ranging from two wheelers – which could prompt more users to switch to electric – to heavy-duty transport.[107]

Regulators and policymakers must ensure that whatever standards they set are grounded in real-world performance, and are continually monitored to bridge the gap between 'rated' and 'actual' performance. Integrating digital technologies can streamline compliance monitoring; penalties should be strictly enforced and transparent reporting insisted upon. Fuel economy standards should be aligned with other regulatory processes, such as exhaust emissions and fuel quality norms.[108]

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India's road logistics sector is hindered by outdated vehicles and a fragmented market structure, leading to inefficiencies such as poor fuel efficiency, unnecessary trips, and vehicle overloading.[109] Streamlined logistical operations could substantially reduce emissions. The Centre and state governments should collaborate with manufacturers to periodically revise fuel and emission standards for trucks and ensure practicality and timely enforcement, with regular monitoring of road performance.[110] The location of future warehouses can also be improved by utilising data from the GST e-way bill system to optimise logistics.[111] Private logistics operators, on their part, should maximise truck capacity utilisation, regularly upgrade outdated vehicles, improve warehouse locations, minimise empty trips, and employ larger trucks where feasible. Economic incentives can encourage owners to retire older trucks.

Employ Data Availability and Modelling

Developing a comprehensive dataset encompassing key variables essential for modelling and understanding the pathways for energy transition in the country is vital to analysing transportation demand and energy consumption, making long-term projections, and designing transformative policies.[112] India's Ministry of Statistics and Programme Implementation (MoSPI) must establish a data collection framework dedicated to the transport sector, involving diverse stakeholders from government and civil society, academia, transport engineers, think tanks and modelling teams. The framework must facilitate systematic data collection and analysis of short- and long-distance travel behaviour, energy consumption by vehicle type, the number of vehicles categorised by type and emission standard, load factors, and service demand for passenger vehicles and freight transport. Such a harmonious dataset will ensure consistency across different models.[113]

The overarching challenges in reducing road transport emissions have been discussed, but there are many specific circumstances in which corresponding solutions may differ significantly. A toolset is needed which can conduct context-specific diagnosis of the barriers and solutions associated with particular renewable fuels, electricity, and low-carbon vehicles. This would help policymakers formulate appropriate policy and regulatory frameworks. The proposed toolset could include a United

Nations Sustainable Development Goals'-aligned benchmarking framework allowing comparison of technological options and their impacts on the energy and transport systems. It should incorporate indicators such as cost-per-passenger-kilometre (PKM) or ton-kilometre (TKM), employment impact (jobs created versus jobs lost due to transition), and the corresponding emission reductions per PKM or TKM for each technology option.[114] It should also provide decision trees outlining how pathways for transport decarbonisation and renewable energy integration can be translated into specific policies, contingent upon prevailing conditions.

Conclusion

The transition to a decarbonised transport sector in India is both a complex challenge and an opportunity for sustainable development. Addressing the sector's rising emissions and energy demands—driven by the widespread reliance on internal combustion engine vehicles and the rapidly growing freight industry—is critical.

Key interventions have the potential to steer the sector toward sustainability. These include accelerating the adoption of EVs, fostering NMT such as walking and cycling, integrating renewable energy into the transportation ecosystem, and transitioning to alternative, low-carbon fuels. Achieving these objectives will require institutional reforms and enhanced coordination among ministries, municipal authorities, and private stakeholders. Policies emphasising stricter fuel economy standards, financial incentives for EV adoption, and increased investments in public transport infrastructure must be supported by effective monitoring and evaluation mechanisms. Additionally, adopting innovative urban planning strategies, such as transit-oriented development and active mobility promotion, can contribute to creating sustainable urban transport systems while addressing socioeconomic inequities.

Achieving net-zero emissions in the transport sector by 2070 is not merely a technical task but a strategic imperative. Without cohesive efforts, robust regulatory frameworks, and sustained political commitment, India risks falling short of both its domestic and international climate commitments. This research highlights that collaboration, innovation, and an unwavering resolve are pivotal to achieving a sustainable and resilient transport ecosystem.ORF

Endnotes

1 R. B. Bhagat, *Urbanization In India: Trends, Pattern And Policy Issues,* Mumbai, International Institute of Population Sciences, 2018, https://www.iipsindia.ac.in/sites/default/files/IIPS_Working_Paper_No_17.pdf

2 Government of India, Ministry of Urban Development, *Handbook Of Urban Statistics*, 2016, https://mohua.gov.in/pdf/5853c4c9864675832b25ba492dhandbook%20of%20urban%20statistics.pdf

3 IANS, "Urban Indians To Contribute 75% Of GDP By 2030: Report," *Zee Business News*, August 6, 2019.

4 Ministry of Housing and Urban Affairs, "Level Of Urbanisation," Government of India, https://mohua.gov.in/cms/level-of-urbanisation.php

5 Rai S. Kookana et al., "Urbanisation and Emerging Economies: Issues And Potential Solutions For Water And Food Security," *Science of The Total Environment* 732, 2020, https://www.sciencedirect.com/science/article/pii/S0048969720325742

6 New Delhi, Ministry of Road Transport & Highways, Transport Research wing, *Road Transport Year Book (2019 - 20)*, https://morth.nic.in/sites/default/files/RTYB_Publication_2019_20%20(1).pdf

7 Namita Singh et.al., "Projection of Private Vehicle Stock in India Up to 2050," *Transportation Research Procedia*, 2018, https://www.wctrs-society.com/wp-content/uploads/abstracts/mumbai/WCTR2019_Mumbai_641.pdf

8 New Delhi, Ministry of Road Transport & Highways, Transport Research wing, *Road Transport Year Book (2019 - 20)*

9 New Delhi, Ministry of Road Transport & Highways, Transport Research wing, *Road Transport Year Book (2019 - 20)*

10 Sanjay Singh, "Review of Urban Transportation in India," *Journal of Public Transportation 8*, no. 1 (2005), https://www.sciencedirect.com/science/article/pii/S1077291X22003563

11 INAE Forum on Civil Infrastructure, *Urban Transportation Challenges and Way Forward,* August 2019, https://www.inae.in/storage/2020/01/Urban-Transportation.pdf

12 New Delhi, Ministry of Urban Development, Government of India, *Recommendations of Working Group on Urban Transport for 12th Five Year Plan,* https://www.mohua.gov.in/upload/uploadfiles/files/UT_FYP_12.pdf

13 Vincent Chin et al., *Unlocking Cities The impact of Ridesharing Across India*, The Boston Consulting Group, 2018, https://web-assets.bcg.com/img-src/BCG-Unlocking-Cities-Ridesharing-India_tcm9-185213.pdf

Endnotes

14 "Unlocking Cities The impact of Ridesharing Across India"

15 "21 of the World's 30 Cities With the Worst Air Pollution are in India," *CNN news*, https://edition.cnn.com/2020/02/25/health/most-polluted-cities-india-pakistan-intl-hnk/index.html

16 "Transport Sector Accounts For 40 Per Cent Of Air Pollution; Need To Develop Greener Fuels: Gadkari," *The Economic Times*, May 25, 2023, https://economictimes.indiatimes.com/industry/renewables/transport-sector-accounts-for-40-per-cent-of-air-pollution-need-to-develop-greener-fuels-gadkari/articleshow/100509892.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

17 Vikas Singh et al., "Exceedances And Trends Of Particulate Matter (PM2.5) In Five Indian Megacities," *Science of the Total Environment* 750, 2021, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7417276/

18 Sarath K. Guttikunda et al., "Re-Fueling Road Transport For Better Air Quality In India," *Energy Policy* 68, 2014, https://sci-hub.se/https://www.sciencedirect.com/science/article/abs/pii/S0301421514000020?via%3Dihub

19 S. Steinleet al., "Personal Exposure Monitoring Of PM2.5 In Indoor And Outdoor Microenvironments," *Science of the Total Environment* 508, 2015, https://www.sciencedirect.com/sdfe/reader/pii/S0048969714017057/pdf

20 Parveen Kumar commented on "Abating Transport Emissions With Electric Vehicle Adoption in India," WRI India, 2021, https://www.wricitiesindia.org/content/abating-transport-emissions-electric-vehicle-adoption-india

21 The International Council on Clean Transportation, *Health Impacts of Air Pollution From Transportation Sources In Delhi*, 2019, https://theicct.org/wp-content/uploads/2022/01/ICCT_factsheet_health_impact_airpollution_Delhi_20190705.pdf

22 India Air Quality Index, "Real time PM2.5, PM10 air pollution level," https://www.aqi.in/in/dashboard/india

23 Puneet Kamboj et al., *Transport Energy Outlook*, CEEW: The Council, 2022, https://www.ceew.in/sites/default/files/ceew-research-transport-energy-use-carbon-emissions-decarbonisation.pdf

24 International Energy Agency, *Transitioning India's Road Transport Sector Realising Climate and Air Quality benefits*, NITI Ayog, 2020, https://iea.blob.core.windows.net/assets/06ad8de6-52c6-4be3-96fc-2bdc3510617d/TransitioningIndiasRoadTransportSector.pdf

25 Megha Kumar et al., *Decarbonising India's Road Transport: A Meta-Analysis Of Road Transport Emissions Model*, The International Council of Clean Transportation, 2022, https://theicct.org/wp-content/uploads/2022/05/Meta-study-India-transport_final.pdf

Endnotes

26 Arunima Bharadwaj, "India's Oil & Gas Import Bill Likely To Double In 15 Years: PPAC," *Financial Express,* February 15, 2024, https://www.financialexpress.com/policy/economy-indias-oil-amp-gas-import-bill-likely-to-double-in-15-years-ppac-3394699/

27 Bharadwaj, "India's Oil & Gas Import Bill Likely to Double In 15 Years: PPAC"

28 NDC Cluster, *Promoting The Uptake Of Electric Vehicles To Reduce Pollution In Beijing City, China*, 2018, https://api.knack.com/v1/applications/5b23f04fd240aa37e01fa362/download/asset/5cd198a4a8724400062dd14a/190502_gpd_parisabkommen_china_05.pdf

29 James Thoem, "What Makes Copenhagen The World's Most Bicycle Friendly Capital?," https://www.visitcopenhagen.com/copenhagen/activities/what-makes-copenhagen-worlds-most-bicycle-friendly-capital

30 Pallav Purohit et al., "Decarbonizing India's Road Transportation Brings Major Co-Benefits, Notably Reducing Air Pollution," *International Institute for Applied System Analysis News,* August 8, 2023, https://iiasa.ac.at/news/aug-2023/decarbonizing-indias-road-transportation-brings-major-co-benefits-notably-reducing

31 Ministry of Environment, Forest and Climate Change, Government of India, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1945472#:~:text=India%2C%20at%20the%2026th%20session,achieve%20net%20zero%20by%202070

32 Credit Rating Information Services of India Limited, *All-India Study On Sectoral Demand For Petrol And Diesel Final Report | (October 2020 – September 2021)*, 2021, https://ppac.gov.in/uploads/whatsnew/1663838452_ExecutiveSummarySectoralConsumptionStudy.pdf

33 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits

34 New Climate institute and Climate analytics, *Decarbonising The Indian Transport Sector Pathways And Policies*, 2020, https://climateactiontracker.org/documents/832/CAT_2020-12-09_Report_DecarbonisingIndianTransportSector_Dec2020.pdf

35 The Energy and Resource Institute, *Decarbonization Of Transport Sector In India: Present Status and Future Pathways*, Children Investment Fund Foundation, 2021, https://www.teriin.org/sites/default/files/files/Decarbonization_of_Transport%20Sector_in_India.pdf

36 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits, July 2020"

37 "Decarbonising The Indian Transport Sector Pathways and Policies, 2020"

38 "Decarbonising The Indian Transport Sector Pathways and Policies, 2020"

39 "Decarbonising The Indian Transport Sector Pathways and Policies, 2020"

Endnotes

40 "Decarbonising The Indian Transport Sector Pathways and Policies, 2020"

41 "Decarbonising The Indian Transport Sector Pathways and Policies, 2020"

42 WRI India, *Decarbonization of Transport Sector In India: Present Status And Future Pathways*, August 2024.

43 "Decarbonization of Transport Sector in India: Present Status and Future Pathways"

44 "Decarbonization of Transport Sector in India: Present Status and Future Pathways"

45 "Decarbonization of Transport Sector in India: Present Status and Future Pathways"

46 "Decarbonization of Transport Sector in India: Present Status and Future Pathways"

47 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits, July 2020"

48 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits, July 2020"

49 Ministry of Coal, Government of India, "Production & Supplies," https://coal.gov.in/en/major-statistics/production-and-supplies#:~:text=The%20all%20India%20Production%20of%20coal%20during%202023%2D24%20was,a%20positive%20growth%20of%2012.94%25

50 Jayantha Mitra et al., *Just Transition Framework for a Sustainable Future in India's Coal Mining Regions. The Energy and Resources Institute*, 2023, https://teriin.org/sites/default/files/2024-02/Just%20Transition%20Framework%20for%20a%20Sustainable%20Future%20in%20India%E2%80%99s%20Coal%20Mining%20Regions.pdf

51 Souvik Bhattacharjya et al., *Assessing Vulnerability From Coal Dependence and Need for a Just Transition,* New Delhi, The Energy and Resources Institute, 2021, https://www.teriin.org/sites/default/files/2021-06/Coal-Dependence-Need-Just-Transition_WP1.pdf

52 NITI Aayog and Ministry of Petroleum and Natural Gas, *Roadmap For Ethanol Blending In India 2020-2025*, 2021, https://www.niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf

53 Promit Mookherjee, "Addressing Feedstock Challenges To Unlock India's Biofuel Potential," Observer Research Foundation, 2024, https://www.orfonline.org/expert-speak/addressing-feedstock-challenges-to-unlock-india-s-biofuel-potential

54 "Driving India's Clean Energy Transition with Biofuels," Intueri Consulting, https://intueriglobal.com/driving-indias-clean-energy-transition-with-biofuels/

55 Society of Indian Automobile Manufacturers (SIAM), *Vision And Recommendations – Alternative Fuels In India*, 2019, https://www.siam.in/uploads/filemanager/159SIAMWhitePaperonAlternativeFuelsforvehicles.pdf

Endnotes

56 Bandyopadhyay et al., "Methanol – As a Future Alternative Fuel for Indian Automotive," *SAE Technical Paper*, 2024, https://www.researchgate.net/publication/377437088_Methanol_

57 M.R. Nouni et al., "Alternative Fuels For Decarbonisation Of Road Transport Sector In India: Options, Present Status, Opportunities, And Challenges," *Fuel* 305, 2021, https://www.sciencedirect.com/science/article/abs/pii/S0016236121014642

58 Nouni et al., "Alternative Fuels for Decarbonisation of Road Transport Sector In India: Options, Present Status, Opportunities, And Challenges"

59 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits. July 2020"

60 Shreyans Jain, "Financing India's Green Transition," 2023, https://www.orfonline.org/research/financing-indias-green-transition-60753

61 Anurag Garg, "India's Solar Energy Sector: Challenges, Opportunities, And Future Prospects," *PV Magazine,* June 5, 2024, https://www.pv-magazine-india.com/2024/06/05/indias-solar-energy-sector-challenges-opportunities-and-future-prospects/

62 Olusola Joshua et al., "Legal Responses To Energy Security And Sustainability In Nigeria's Power Sector Amidst Fossil Fuel Disruptions And Low Carbon Energy Transition," *Heliyon* 9, 2023, https://www.sciencedirect.com/science/article/pii/S2405844023051204

63 Office of NEPA policy and compliance, "The National Environmental Policy Act of 1969," https://www.energy.gov/nepa/articles/national-environmental-policy-act-1969

64 "Why Regulatory Hurdles Need To Be Overcome For Clean Energy Expansion," *World Economic Forum,* March 19, 2024, https://www.weforum.org/agenda/2024/03/regulatory-hurdles-clean-energy-transition/

65 Wuppertal Institute for Climate, Environment and energy, "The German Energiewende A Transition Towards An Efficient, Sufficient Green Energy Economy, International Institute For Industrial Environmental Economics Wuppertal Institute For Climate," *Environment and Energy, 2015,* https://epub.wupperinst.org/frontdoor/deliver/index/docId/6107/file/6107_Energiewende.pdf

66 Indian National Academy of Engineering, Department of Science and Technology, Government of India, *INAE-DST Meeting on Clean Coal Technologies* (India: Indian National Academy of Engineering, 2016), https://www.inae.in/wp-content/themes/fortuna-child/img/Final%20Report%20on%20Clean%20Coal%20Tech.pdf

Endnotes

67 Maruxa Cardama and Alice Yiu, *Engagement of Transport Stakeholders in the United Nations Framework Convention on Climate Change,* SLOCAT, https://tcc-gsr.com/wp-content/uploads/2023/09/Spotlight-3-Engagement-of-Transport-Stakeholders-in-the-United-Nations-Framework-Convention-on-Climate-Change-Process.pdf

68 United Nations, *Establishment Of An Inter-Ministerial Committee On Sustainable Consumption And Production In Chile,* UN Environment, https://www.oneplanetnetwork.org/sites/default/files/case_studies.pdf

69 Energy data, "Energy Dilemma: Balancing Economic Growth With Decarbonisation," Energy Data, 2023, https://d1owejb4br3l12.cloudfront.net/publications/executive-briefing/india-economic-growth-decarbonisation.pdf

70 Planning commission, Government of India, *India Transport Report: Moving India to 2032* (India: Planning commission, 2014) http://164.100.161.239/sectors/NTDPC/voulme3_p2/urban_v3_p2.pdf

71 Prime Ministers Council on Climate Change, Government of India, *National Action Plan on Climate Change,* 2018, https://moef.gov.in/uploads/2018/04/NAP_E.pdf

72 Ministry of Road Transport and Highways, Government of India, *Green Highways (Plantation, Transplantation, Beautification & Maintenance),* 2015, https://morth.nic.in/sites/default/files/Green_Highways_Policy.pdf

73 Ministry of Road Transport and Highways, Government of India, "Vehicle Scrapping Policy –Overview," https://morth.nic.in/vehicle-scrapping-policy-overview

74 Ministry of Power, Government of India, *Charging Infrastructure for Electric Vehicles* (New Delhi: Ministry of Power,2022), https://powermin.gov.in/sites/default/files/Final_Consolidated_EVCI_Guidelines_January_2022_with_ANNEXURES.pdf

75 Ministry of Power, Government of India, https://pib.gov.in/PressReleasePage.aspx?PRID=1542246

76 Ministry of Heavy Industries & Public Enterprises, Government of India, "The Production Linked Incentive (PLI) Scheme for Automobile and Auto components," https://heavyindustries.gov.in/pli-scheme-automobile-and-auto-component-industry

77 Ministry of Heavy Industries & Public Enterprises, Government of India, "Faster Adoption & Manufacturing of Electric Vehicles in India," https://heavyindustries.gov.in/fame-ii

78 Ministry of Heavy Industries & Public Enterprises, Government of India, https://pib.gov.in/newsite/printrelease.aspx?relid=116719

79 Ministry of New and Renewable Energy, Government of India, "National Green Hydrogen Mission," https://mnre.gov.in/national-green-hydrogen-mission/

Endnotes

80 Ministry of petroleum and Natural Gas, Government of India, "Sustainable Alternative Towards Affordable Transportation," https://mopng.gov.in/en/pdc/investible-projects/alternate-fuels/sustainable-alternative-towards-affordable-transportation

81 Ministry of petroleum and Natural Gas, Government of India, "Ethanol Blended Petroleum Program," https://mopng.gov.in/en/refining/ethanol-blended-petrol

82 Prime Ministers Council on Climate Change, Government of India, *National Action Plan on Climate Change*

83 Ministry of Housing and Urban Affairs, Government of India, "Smart City Mission," https://smartcities.gov.in/

84 Ministry of Urban Development, Government of India, *Operations Document for Urban Transport Fund (UTF)*, (New Delhi: Ministry of Urban Development, 2016), https://mohua.gov.in/upload/uploadfiles/files/UTF_v13.pdf

85 Ministry of Urban Development, Government of India, *National Transit Oriented Development Policy* (New Delhi: Ministry of Urban Development, 2018), https://mohua.gov.in/upload/whatsnew/59a4070e85256Transit_Oriented_Developoment_Policy.pdf

86 Lydia Powell, "India's Tax Revenue From Petroleum Products: Golden Eggs That May Kill The Goose?," Observer Research Foundation, November 18, 2020, https://www.orfonline.org/expert-speak/indias-tax-revenue-from-petroleum-products#:~:text=The%20importance%20of%20tax%20revenue,during%20in%20the%20last%20decade

87 "Decarbonization of Transport Sector in India: Present Status and Future Pathways"

88 N. Dawda, "Study on Barriers and Policy Interventions for Adoption of Integrated and Sustainable Multimodal Transport System in Indian Metropolitan Cities" (Ph.D. thesis, Sardar Vallabhbhai National Institute of Technology, 2023) http://hdl.handle.net/10603/529939

89 Dawda, "Study on Barriers and Policy Interventions for Adoption of Integrated and Sustainable Multimodal Transport System in Indian Metropolitan Cities"

90 Asian Development Bank, *Public Private Partnership Monitor: Indonesia*, 2020, https://www.adb.org/sites/default/files/publication/688886/public-private-partnership-monitor-indonesia.pdf

91 International Capital market association, *Overview and Recommendations for Sustainable Finance Taxonomies*, 2021, https://www.icmagroup.org/assets/documents/Sustainable-finance/ICMA-Overview-and-Recommendations-for-Sustainable-Finance-Taxonomies-May-2021-180521.pdf

Endnotes

92 Climate Bonds Initiative and China Central Depository & Clearing Research Centre (CCDC Research), *China Green Bond Market Report*, 2021, https://www.climatebonds.net/files/reports/cbi_china_sotm_2021_0.pdf, Government of India, *Framework for Sovereign Green Bonds Government of India,* 2022, https://dea.gov.in/sites/default/files/Framework%20for%20Sovereign%20Green%20Bonds.pdf

93 Green Finance Platform, "Indonesia Green Taxonomy Edition 1.0," https://www.greenfinanceplatform.org/policies-and-regulations/indonesia-green-taxonomy-edition-10#:~:text=In%20January%202022%2C%20the%20Financial,and%20prevent%20green%20washing%20practices

94 Government of India, *Framework for Sovereign Green Bonds,* 2022, https://dea.gov.in/sites/default/files/Framework%20for%20Sovereign%20Green%20Bonds.pdf

95 Questions of Cities, "How Most Indian Cities Moved From Public To Private Transport Modes," https://questionofcities.org/how-most-indian-cities-moved-from-public-to-private-transport-modes/

96 Ministry of Road Transport and Highways, *Road Accident in India 2022,* 2022, https://morth.nic.in/sites/default/files/RA_2022_30_Oct.pdf

97 Ola Mobility Institute, "Ease of Moving Index Dashboard," https://easeofmoving.org/

98 Nandan Dawda et al., "Efficiency Based Evaluation of Public Transport and Paratransit Systems with a View to Integrating Transportation," *Transportation Research Record: Journal of the Transportation Research Board* 2675, 2020, https://journals.sagepub.com/doi/abs/10.1177/0361198120980322

99 Nandan Dawda et al., "Evaluating Policy Interventions to Overcome Barriers for Designing an "Integrated Multimodal" and "Sustainable" Urban Transport System: A Hybrid Fuzzy SWARA – Fuzzy WASPAS Approach," SSRN, https://ssrn.com/abstract=4196522

100 Brussels European Union, "Cycling Copenhagen: The Making of a Bike-Friendly City," https://eu.boell.org/en/cycling-copenhagen-the-making-of-a-bike-friendly-city

101 Things to do in Amsterdam , "Cycling in Amsterdam," https://thingstodoinamsterdam.com/transport/cycling-in-amsterdam/

102 Amsterdam City Council / CTO-Office and Smart City , "Perspectives on the Future of Mobility in Amsterdam," 2018, https://openresearch.amsterdam/image/2019/7/25/future_of_mobility.pdf

103 Railway Technology, "Paris Metro, Île-de-France," 2020, https://www.railway-technology.com/projects/paris-metro-france/?cf-view

104 C40 knowledge hub, "Benchmark 15 Minutes Cities," 2022, https://www.c40knowledgehub.org/s/article/Benchmark-15-minute-cities?language=en_US

Endnotes

105 National Climate Change Secretariat, "TRANSPORT," Strategy group prime minister office, https://www.nccs.gov.sg/singapores-climate-action/mitigation-efforts/transport/

106 Global fuel Economy initiative, Securing *Global Fleet Transformation GFEI's Zero Pathway*, 2021, https://www.globalfueleconomy.org/media/792020/gfei-zero-pathway-report-2021-final-spreads.pdf

107 "Transitioning India's Road Transport Sector Realising Climate and Air Quality Benefits, July 2020"

108 Aviral Yadav et al., *Heavy-Duty Trucks In India: Technology Potential and Cost-Effectiveness of Fuel-Efficiency Technologies in the 2025–2030 Time Frame,* The International Council of Clean Transportation, 2023,https://theicct.org/wp-content/uploads/2023/06/India-HDT-fuel-efficiency_FINAL.pdf

109 NITI AYOG and RMI, *Fast Tracking Freight in India: A Roadmap for Clean and Cost-Effective Goods Transport,* 2021, https://www.niti.gov.in/sites/default/files/2021-06/FreightReportNationalLevel.pdf

110 Center for Science and Environment, *Trucks: Heavy Duty Pollution And Actions,* 2016, https://shaktifoundation.in/wp-content/uploads/2017/06/CSE-2016-Trucks-Heavy-duty-pollution-and-action.pdf

111 Authbridge, "E-Way Bill And Warehouse Management," https://authbridge.com/knowledge-centre/insights/eway-bill-warehouse-management

112 Miguel Chang et al., "Trends In Tools And Approaches For Modelling The Energy Transition," *Applied Energy* 290, 2021, https://www.sciencedirect.com/science/article/pii/S0306261921002476

113 Anantha Lakshmi Paladugulaa et al., "A Multi-Model Assessment Of Energy And Emissions For India's Transportation Sector Through 2050," *Energy Policy* 116, 2018, https://www.sciencedirect.com/science/article/abs/pii/S0301421518300466

114 Siddarth Durga et al., "Developing New Pathways For Energy And Environmental Decision-Making In India: A Review," *Environmental Research Letters* 17, 2022, https://doi.org/10.1088/1748-9326/ac6f13

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