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Comparison of Decarbonisation Strategies for India's Land Transport Sector: An Inter Model Assessment

April, 2019

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Abbreviations

BEE	Bureau of Energy Efficiency
CAGR	Compound Annual Growth Rate
CEEW	Council on Energy, Environment and Water
CMP	Common Modelling Protocol
CO_2	Carbon Dioxide
CSTEP	Center for Study of Science, Technology and Policy
GCAM	Global Change Assessment Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GoI	Government of India
HHDT	Heavy Heavy-Duty Truck
IAM	Integrated Assessment Model
IESS	India Energy Security Scenarios Model
IMC	Inter Model Comparison
IRADe	Integrated Research and Action for Development
IRADe–AA	IRADe Activity Analysis
LDV	Light Domestic Vehicle
LHTD	Light Heavy-Duty Truck
MHDT	Medium Heavy-Duty Truck
MoEFCC	Ministry of Environment, Forest and Climate Change
MoPNG	Ministry of Petroleum and Natural Gas
MoRTH	Ministry of Road Transport and Highways
NDC	Nationally Determined Contribution
NITI Aayog	National Institution for Transforming India
NMT	Non-Motorized Transport
NTDPC	National Transport Development Policy Committee
PKM	Passenger Kilometre
PM2.5	Particulate Matter
PNNL	Pacific Northwest National Laboratory
PPAC	Petroleum Planning and Analysis Cell
SGWG	Sustainable Growth Working Group
SSEF	Shakti Sustainable Energy Foundation
TEDDY	TERI Energy & Environment Data Diary and Yearbook
TERI MARKAL	TERI's MARket ALlocation Model
TERI	The Energy and Resources Institute
TKM	Tonne Km
TOD	Transit-Oriented Development
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

Executive Summary

This report provides the results of an inter-model comparison exercise undertaken by five modelling teams to analyse the future growth of India's transport sector and to evaluate the role of various transport sector policies in reducing=transport related energy & emissions in India.

The research teams, based on consultations with the advisory board, the internal steering committee, and various other stakeholders, modelled three scenarios to reflect the implications of select policy-driven strategies that could play a key role in the decarbonisation of India's transport sector. These strategies were included under three scenarios, namely, Reference, New Policy scenario, and High Ambitions scenario. The Reference scenario is a representation of status quo where the current trends in policies continue. In the New Policy scenario, the underlying assumption is that the Government of India (GOL) targets, as set out by the policies, are fully effective and achieved. The High Ambitions scenario assumes that the GoI policy targets are exceeded.

Further, under the new policy and high ambitions targets as delineated by the internal steering committee, the modelling teams evaluated five main decarbonisation strategies, Namely, Modal Shift, Fuel-efficiency Improvements, Electrification, Biofuel Blending, and Moderation in transport demand. It may be noted that only rail- and road-based transportation movement was taken up for analysis in this exercise (They together account for more than 90% of the current emissions in the sector). Shift to rail in freight movement was not included across all the models.

In the Reference scenario, the modelling teams estimate that the transport energy demand would grow rapidly at a CAGR of 5.1%–7.9% between 2010 and 2030, and then slow down to a CAGR of 4.2%–6.7% by 2050. Within passenger transport, cars and two-wheelers are expected to meet most of the passenger-transportation requirements. This trend is expected to be driven by increasing ownership of private motorized vehicles as a consequence of rising household incomes. The energy demand for freight transport is estimated to grow by 6 to 10 times between 2010 and 2050, primarily on account of increased economic activity.

Additionally, in the Reference scenario, passenger and freight modes continue to be largely driven by fossil fuels, and, consequently, reflect a large increase in the overall emissions. Models project that transport-related CO_2 emissions are expected to grow at a CAGR of 4.9%–7.8% and could be in the range of 378 MT to 833 MT in 2030, as compared to CO_2 emissions of 153 MT to 199 MT in 2010. In the passenger sector, cars and two-wheelers account for a dominant share of the CO_2 emissions. With regard to freight transport, the models envisage that on an average freight-transport emissions are likely to contribute to half of the transport sector's emissions in 2030. Additionally, models also forecast a relatively lower reduction in the energy intensity of freight service. This indicates the need for targeted policy action for improving energy efficiency and modal shifts to cleaner modes of transport in the freight sector.

In the Reference scenario, all models indicate that the decline in the transport-emission intensity of energy will be negligible even up to 2050, highlighting that low-carbon options need to be prioritized in both passenger and freight transport.

This study addresses long-term implications of the potential realization of decarbonisation policies in the transportation sector. The scenarios were designed to explore the effects of different policies on final energy consumption and CO_2 emissions. The study does not address the issues of a roadmap for these strategies. Since it is not a cost-benefit analysis, the modelling teams did not estimate the costs of refining and fuelling infrastructure, investments in public transportation or the cost of technology. The modelling teams did not incorporate policy changes in energy production into the analysis of transportation policies. All policy scenarios were modelled with the BAU energy mix.

The results of the scenarios modelled across various modelling teams (Tables 0.1 and 0.2) indicate that fuel efficiency and modal shifts (shift from private vehicles to public modes of transport such as buses and three-wheelers) yield the largest energy and emission savings in

Table 0.1: Change in CO_2 emissions from land transport: New Policy (2030)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2030 (million tonnes)	630	376	378	833	615
Electrification	-2.5%	-26%	-1.2%	-6.6%	-8.1%
Increased efficiency	-8.0%	-12.9%	-9.3%	-38.8%	-20.6%
Modal shift	-10.9%	-4.8%	-2.1%	-4.5%	-5.8%
Moderating demand	-6.1%	-6.4%	-4.2%	-7.8%	-6.2%
Alternative fuels	-5.0%	-7.6%	-14.8%	-8.3%	-5.9%

Table 0.2: Change in CO_2 emissions from land transport: High Ambitions (2030)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2030 (million tonnes)	630	376	378	833	615
Electrification	-6.2%	-24.3%	-5.0%	-11.5%	-18.5%
Increased efficiency	-16.4%	-15.3%	-7.5%	-44.9%	-24.8%
Modal shift	-19.7%	-4.8%	-4.7%	-5.0%	-13.5%
Moderating demand	-9.2%	-9.5%	-4.5%	-9.7%	-9.3%
Alternative fuels	-6.5%	-17%	-27.5%	-12.7%	-8.3%

the transport sector[1]. Outcomes of the analysis also push for electrification and suggest gradual uptake of alternative fuels in order to further decarbonise the sector. Additional analysis undertaken by a few modelling teams indicates that if modal shifts towards rail in freight movement were also included, then the strategy of modal shifts would be much more effective than energy efficiency. Further, the analysis also indicated that decarbonisation of the power sector, along with increased electrification of the transport sector, could provide significant benefits in terms of emission reduction.

The analysis of the modelling groups also indicated that with consistent efforts towards efficiency, cleaner fuels, electrification, and other modelled strategies, the transport sector has the potential to reduce India's dependence on crude-oil imports, and contribute to a reduction in tailpipe particulate emissions. Reducing PM2.5 emissions[2] can limit on-road exposures and reduce premature mortality and respiratory ailments.

Going forward, India is expected to witness an unprecedented growth in both passenger- and freight-transport energy demands and our dependence on fossil fuels is likely to continue. The current transport-sector policies may not be too effective in reducing the emission intensity of GDP in the transport sector by 2030. An integrated multipronged approach towards decarbonising the transport sector is required from the government. Greater emphasis on efficiency improvement and enhanced investment in public transport system, as well as greener modes of transport, can help reap significant benefits. Massive policy push, either in the form of subsidies,taxes or regulations is required to achieve the above.

[1]Investigation into the cost aspect of enhancing the vehicle fleet's efficiency has not been taken up under the study. The authors would also like to highlight that the benefits of efficiency improvement could be offset by increases in the stock of vehicles and service demand. The teams modelled the scenarios with various degrees of precision compared to the goals in the CMP.

[2] PM2.5 emissions are fine particles whose diameter is less than or equal to 2.5 μm.

Introduction

Following the Paris Agreement in December 2015, India has, through its Nationally Determined Contributions (NDCs), pledged to reduce its emission intensity of GDP by 33%–35% by 2030, compared to the 2005 levels. This draws attention towards the energy and emission-intensive sectors in view of the growth potential in activities associated with various sectors, and the possibility of adopting alternative fuel and technology choices across each of these.

Transport sector plays a pivotal role in augmenting the economic growth of a country owing to its role in connecting countries, states, cites, and so on, and fostering inter and intra-regional trade. However, it is important to highlight that growth in both passenger mobility and freight movement is likely to have far-reaching implications in terms of increased energy consumption and greenhouse gas (GHG) emissions as well as local pollutants.

In 2017–18, the transport sector was the second-largest energy consumer in India, accounting for around 24% of the country's total energy consumption (TEDDY, 2018) and contributing to around 10% of the total GHG emissions[3], an increase of 22% from the 2007 levels (MoEFCC, 2015). Despite improvements in technical efficiencies across modes of transport, the growth in mobility demand, as well as the change in modal shares between road and rail or public and private vehicles, has resulted in an increasing fuel-consumption trend in the transport sector. During 2005–2015, the energy consumption in India's transport-related activities increased at a CAGR of 8.3%—a much higher rate than the fuel consumption in the transport sector globally (CAGR of 2%) during the same period (IEA, 2019). Also, with high growth of private vehicle ownership and continued dependence on conventional fossil fuels like petrol and diesel, emissions from the sector have been increasing. The World Bank estimated that the share of transport-related emissions in total emissions from fuel combustion decreased globally from 22% to 20.4% during 2000–2014, but the corresponding share in India grew from 10.7% to 11.5% in same period of time[4] (The World Bank, 2019). Accordingly, the transport sector holds an important place in terms of how the relative share of resultant emissions may change and how it may influence India's NDC targets in the future.

Going forward, India is expected to continue moving forward with robust economic growth (GDP) along with a population that is still increasing. A large share of this growth is expected to be led by the industrial and service sectors, leading to increased transport activity in both passenger and freight segments. The future increase in transport demand, in terms of passenger kilometres (pkm) and tonne kilometres (tkm) can, therefore, have far-reaching implications on GHG emissions, energy security, and infrastructural planning and development. Therefore, appropriate mitigation and adaptation strategies in the transport sector must play an important role by contributing significantly to address these challenges, while meeting the increasing mobility demands of the country. This becomes even more important with India's commitment to the Paris Agreement in terms of its NDCs. India is already focusing on several initiatives geared towards energy-efficient and low-carbon transport systems to reduce emissions from the transport sector, like introduction of mass transit systems, fuel economy norms, electric mobility, improved emission standards, etc. While the largest benefits of mitigation actions across sectors seem to be on account of the increasing share of renewables and due to energy-efficiency improvements, there are several other initiatives across sectors as well, such as the vehicle-fuel-efficiency improvement programme and fuel blending targeted towards the transport sector (NDC Registry, 2015).

Conventionally, transport planning decisions pay attention to local and domestic concerns such as air pollution, nature of demand for transport services, and energy-security considerations—studies have shown that mitigation strategies in the sector can also yield the above as co-benefits (NTDPC, 2013; GoI, India Energy Security Scenarios, 2015). From the national standpoint, the emphasis now is to make the sector environmentally sustainable with due attention to national energy and fuel security. The impact of future technology and policy options affecting these agendas should be evaluated to enable policymakers to make informed decisions. To enable this, integrated energy-economy-environment models can aid in quantitative assessments. Against this background, this study, an inter-model comparison of transport-related energy and emissions, seeks to analyse the future growth of India's transport sector and its implications.

Recognizing the importance of energy modelling for effective policymaking for low-carbon growth, the governments of India and the US have formed the SGWG as a part of the bilateral energy dialogue. Following up on this, an inter-model comparison exercise of transport-related energy and emission was taken up to analyse the future growth of India's transport sector. Four research organisations in India (CEEW, CSTEP, IRADe, and TERI) and one from the US (PNNL), led by the NITI Aayog, conducted this study to evaluate the role of various transport-sector policies in reducing transport-related energy and emissions in India. Each institute has integrated energy-economy-

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[3] *In terms of CO_2 equivalent*

[4] *CO_2 emissions from transport include emissions from the combustion of fuel for all transport activity, regardless of the sector, except for international marine bunkers and international aviation.*

environment models distinct from the other, owing to several reasons, including variations in the embedded modelling framework, model structure, input parameters, level of technology disaggregation, and their inherent capabilities and limitations.

Objective

This study aimed at research collaboration amongst four Indian modelling teams (refer to the section 'Institutional Arrangement') for undertaking inter-model comparisons of select transport-sector policies in light of India's NDC targets. The teams analysed a set of technology and policy options that could have implications in terms of reducing energy consumption and emissions, improving access to mobility, and addressing mobility planning in the transport sector. The analysis seeks to inform decision makers regarding the scope of various transport-sector strategies related to energy and emission reduction, improved access, and mobility planning in sync with India's NDC goals. In particular, the study aimed at:

- Identifying the feasible scenarios for modelling and inter-model comparison in consultation with the advisory board.
- Estimating energy consumption and calculating the emission reduction potential of different strategies under different scenarios.
- Initiating a dialogue among the key stakeholders for prioritizing mitigation measures to check emissions from transport sector based on outcomes of the study.

Institutional Arrangement

Modelling teams: Under the SGWG, modelling teams from IRADe, CSTEP, CEEW, and TERI were engaged in a multi-year research collaboration seeking to assist in decision-making through modelling analyses. While each model is fundamentally different, in terms of variations in the embedded modelling framework, model structure, input parameters, level of technology disaggregation, and its inherent capabilities and limitations, the modelling of identical policy problems on different platforms and tools yields a range within which results are obtained providing insights about the robustness of the outcome and the associated uncertainties. This further provides for a more robust consideration of the likely impacts than available from a single model as has been observed in several studies (Clarke et al. 2012; Chaturvedi et al. 2012). It also allows for focused vetting and peer review by helping policymakers understand why different models present different results, and the range of results increases the robustness of the findings. The teams used multiple models as the basis for this research; each team has a core model that simulates economic and/or transport activity and emissions using different approaches.

External technical partner: The participation of PNNL, facilitated by the SGWG, brought forth the experience gained in the US on modelling and policy analysis of energy and carbon emissions of the transport sector. The collaborating partners in this study have already worked on a modelling study evaluating the decarbonisation of the power sector and implications on water resources (Srinivasan et al., 2018) and the transport sector (Paladugula, et al., 2018). PNNL participated in the modelling activities, provided the results, and served as a knowledge partner throughout the process.

Advisory board: NITI Aayog, which represents the GoI at the SGWG, formed an advisory board on transportation and air quality with representatives of the relevant ministries, including MoEFCC, MNRE, several ministries related to the transport sector (the Ministry of Road Transport and Highways [MoRTH], the Ministry of Railways [MoR], the Ministry of Urban Development [MoUD], and DHI), the Petroleum Planning and Analysis Cell (PPAC), the Bureau of Energy Efficiency (BEE), and others (Refer to Annexure 3). The purpose of the advisory board was to guide the teams' modelling efforts by aiding them in setting up the policy targets for different transport-sector strategies. By involving a range of policymakers in inter-model comparison, greater insights regarding the expected progress and challenges across alternative options could be internalized within the scenarios modelled, ensuring higher relevance of the findings.

Internal steering committee: The internal steering committee (ISC), comprising the heads of four organisations and representatives from the NITI Aayog, was formed to guide the modelling team's approach towards the selection of policy strategies that could play a key role in decarbonising India's transport sector. In addition to this, the ISC's role was to ensure that the key outcomes from the study take the form of relevant policy insights.

Methodology, Assumptions, and Limitations

In this study, five energy-economy-environment models have been used to estimate the likely energy and emission implications of various mitigation strategies in the transport sector.

Both PNNL and CEEW have used the Global Change Assessment Model (GCAM). GCAM is a global (multi-region and multi-sector) dynamic-recursive partial equilibrium model with technology-rich representations of the economy, energy sector, land-use, and water linked to a climate model (Kim, Edmonds, Lurz, Smith, & Wise, 2006). CSTEP has used the India Multi-Region TIMES (IMRT) model, which is a bottom-up model based on the MARKAL-EFOM suite of models (Loulou, 2005; Byravan, 2017). The transport module for the IMRT model is a spreadsheet= based accounting model, which is soft-linked to energy flows and emission trajectories of the power-sector module, to achieve consistency in emission trajectories in the decarbonisation scenarios examined in the current study. For this exercise, TERI used the TERI-MARKAL model, which is a dynamic linear-programming (LP) model of a generalized energy system. The model minimizes the overall energy-system costs subject to various constraints to provide the optimal fuel and technology mix under each scenario. IRADe used the IRADe-Integrated Assessment Model (IRADe-IAM), which is a multi sectoral, inter-temporal dynamic optimization model that is bottom-up as it includes alternative technology options, and top-down as it covers the whole macro economy (Pradhan, 2013). Details about the models used by each of the organizations have been provided in Annexure 2.

Common Modelling Protocol

In order to enable a comparison of policy scenarios across the models, there was a need to ensure harmonization of some basic parameters and policy targets. This was achieved by the formulation of the Common Modelling Protocol (CMP) (Annexure 1). Under the protocol, 2010 was chosen as the base year for the modelling exercise as the last inventory of GHG emissions for India are available for this year (MoEFCC, 2015). The protocol also includes a common assumption with respect to socio-economic drivers, such as GDP and population, and the policy targets.

In IRADe's model, GDP is endogenously determined based on certain inherent assumptions for various macroeconomic parameters such as savings rate, labour productivity, and so on. The other four models used exogenous GDP growth trajectories based on NITI Aayog's India Energy Security Scenarios (IESS). Three GDP growth scenarios—low, medium, and high were considered, with corresponding CAGRs of 5.9%, 6.8%, and 7.5%, for the period 2012–2047, respectively. Further, the population projections across all five models was based on the World Population Prospects[5] (UN 2015 Revision), with India's population projected to grow at a CAGR of 0.5% till 2050 from 1.3 billion in 2015.

The common policy targets, as listed in the protocol, were finalized on the basis of one-to-one discussions with the advisory board members (Annexure 4) and literature review of global and Indian policies. As against the Reference scenario, which is characterized by the continuation of the existing trends and where the already existing government policy measures are not fully attained, targets were set for the New Policy and High Ambitions scenario. The New Policy scenario presupposes that the policy targets, as announced by the GoI, are fully effective, while in the High Ambitions scenario, the policy targets set out by the government are exceeded (see Table 1). Keeping in view India's mitigation strategies to reduce emissions from the transport sector, and based on discussions with the advisory board, the following five strategies were finalized and subsequently taken forward for scenario analysis:

1. Electrification of road and rail transport
2. Increased use of alternative fuels, such as ethanol-blended gasoline and biodiesel, in the transport sector
3. Modal shifts:
   - Shift from private to public transport in passenger movement
4. Improved fuel efficiency
   - Improvement in fuel efficiency of light-duty vehicles (LDVs), buses, commercial vehicles, and passenger and freight rail by adopting aggressive fuel-efficiency standards.
5. Moderating demand for passenger and freight movement
   - Reduction in motorized passenger-transport demand by promoting integrated and seamless transport and better urban planning.

[5] *The 2015 Revision (medium variant) by the United Nations Population Division*

Table 1: Common targets for various decarbonisation strategies for the transport sector in New Policy and High Ambitions scenarios

Sl. no.	Strategies	Key elements of strategies	Targets	New Policy scenario			High Ambitions scenario		
				2020	2030	2050	2020	2030	2050
1.	Electrification of transport sector	Electrification of road transport	% share of total battery electric vehicles in new two-wheeler sales	10%	30%	30%	15%	50%	80%
			% share of total battery electric vehicles in new car sales	2%	3%	5%	5%	20%	30%
			% share of total battery electric vehicles in new vehicle sales for buses	2%	10%	20%	5%	20%	40%
			% share of total battery electric vehicles in new vehicle sales for three-wheelers	20%	50%	100%	50%	100%	100%
		Railways electrification	% share of electric traction vs. diesel traction in total passenger movement by rail	60%	70%	80%	80%	90%	100%
			% share of electric traction vs. diesel traction in total freight movement by rail	70%	80%	100%	90%	100%	100%
2.	Increased use of alternative fuels	Increased bio-ethanol blending in petrol	% share of bio-ethanol blending in petrol	4%	10%	10%	7%	20%	20%
		Increased use of bio-diesel in transport	% share of bio-diesel used in transport respectively	0.1%	5%	5%	1.5%	5%	5%
3.	Modal shifts strategy	Increased share of public transport for passenger movement	% share of public transport vehicles vis-à-vis private vehicles in road-based passenger movement	75%	80%	85%	90%	90%	95%
		Increased share of railways	% share of rail transport vis-à-vis road transport in the total passenger movement	15%	15%	15%	20%	20%	20%

Table 1: Common targets for various decarbonisation strategies for the transport sector in New Policy and High Ambitions scenarios

4.	Increased fuel efficiency for various vehicle categories		Four-wheelers (passenger cars of all sizes)	Increase in fuel efficiency by 25% from 2017–18 levels till 2021–22, 15% increase in fuel efficiency from 2021–22 till 2030, then constant at 2030 levels	Increase in fuel efficiency by 30% from 2017–18 levels till 2021–22, 20% increase in fuel efficiency from 2021–22 till 2030, then constant at 2030 levels
			Buses	Increase in fuel efficiency by 25% from 2019–20 till 2030; then constant at 2030 levels	Increase in fuel efficiency by 30% from 2019–20 till 2030; then constant at 2030 levels
			Trucks	Increase in fuel efficiency by 25% from 2019-20 onwards with HDV efficiency norms	Increase in fuel efficiency by 30% from 2019-20 onwards with HDV efficiency norms
			Passenger rail	Improved energy/fuel efficiency in traction from 2013–14 level Improvement in specific energy consumption (SEC): 4.8% in the passenger segment Improvement in specific fuel consumption (SFC): 9.6% in the passenger segment	Improved Energy/Fuel efficiency in traction by 2030 from 2013-14 levels - Improvement in SEC, 8% in passenger segment - Improvement in SFC, 15% in passenger segment
			Freight rail	Improved energy/fuel efficiency in traction from 2013–14 level Improvement in SEC: 13.2% in the freight segment Improvement in SFC: 7.6% in the freight segment	Improved Energy/Fuel efficiency in traction by 2030 from 2013-14 level - Improvement in SEC, 20% in freight segment - Improvement in SFC, 12% in freight segment
5.	Moderating the demand for motorized transport	Moderation in service demand for passenger transport by reducing motorized travel, promoting public transport and non-motorized transport, promoting integrated and seamless transport, better urban planning (compact cities), and reducing the need to travel	Better urban planning and various travel- demand management measures such as telecommuting, compressed work week, flexible schedules, and so on reduces the need for commuting and travel demands.	The travel demand could be reduced through various travel-demand management measures such as telecommuting, compressed work week, flexible schedules, and so on. Literature suggests that several programmes which promote implementing one-day-a-week teleworking across the entire workforce could reduce travel demand by 20%. In this scenario, the demand for motorized transport is expected to reduce by 10% till 2030 and 15% till 2050 from 2015 levels.	In this scenario, the demand for motorized transport is expected to reduce by 15% till 2030 and 20% till 2050 from 2015 levels.

Scope of the Study

In this exercise, only the road and rail segments of the transport sector have been considered, as they account for a dominant share of the passenger and freight movement, energy consumption, and emissions. Specifically, road transport accounts for 87% of the total CO_2 emissions, followed by aviation (7%), railways (4%), and navigation (2%) (TEDDY, 2018). It is important to acknowledge that the growth trajectory of the aviation and navigation sector could have a significant impact on the future emission intensity of the transport sector. However, at present the aviation sector accounts for a very minor share of 0.5%–0.6% of the total passenger and freight traffic (TEDDY, 2018).

Limitations of the Study

In this study, while the five modelling teams used the energy consumption in the transport sector as a common starting point for 2010, the energy-modelling frameworks and assumptions regarding activity levels and efficiencies across modes varied based on the modellers' analysis and judgements.

The modal shift of freight traffic from road to rail transport has not been modelled given the short time frame of the study and other constraints faced by a few models. Accordingly, the results underestimate the decarbonisation potential of modal shift policies as rail transport generally consumes 75%–90% less energy in freight traffic as compared to road-based movement (TERI, 2015).

Further, in estimating the total emissions from electrification of passenger and freight transport, the upstream emissions at the power-generation source have not been considered (although the power sector is not fully decarbonised during the time frame over which increased electrification of transport is considered). This overestimates the decarbonisation potential of electrification as electric vehicles have zero tailpipe emissions.

Discussion of Results

Greater need for mobility has led to an increase in demand for transport services, which has made the transport sector one of the fastest-growing energy users in the country. In 2015–16, the final energy consumption by the transport sector was 86.7 MTOE, which accounted for 24% of the energy consumed by all the sectors in the country (TEDDY, 2018).

Nearly 98.5% of the sector's total energy consumption is met by petroleum products at present (TEDDY, 2016). As per a pan-India study conducted by Nielsen for PPAC, the transport sector accounted for 70% of the diesel and 99.6% of the petrol consumption in 2013. Accordingly, understanding the growth in final energy consumption in the transport sector is critical to arrive at an understanding of the likely level of emission trajectories, as well as to understand the implications for energy security, particularly oil imports, for India.

Reference Scenario Results

Energy consumption

To set up the reference scenario, all modelling teams harmonized the base year (2010) energy consumption (by road and rail) in line with TEDDY estimates. (~ 2.34 EJ) (see Figure 1).

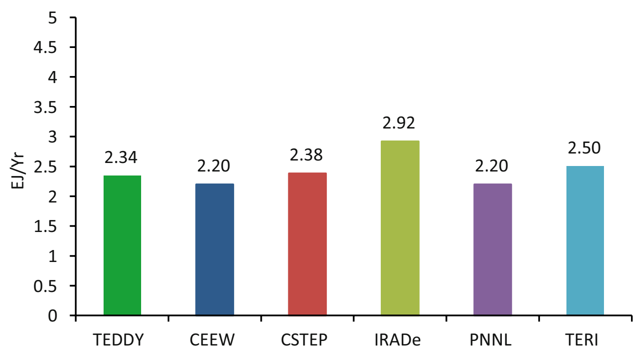

Figure 1: Transport-sector energy consumption (2010)[6]

Starting with a common base, the study has examined how different model structures and differing perspectives regarding alternative options are likely to influence energy and emissions in the transport sector (Figure 2).

Over time, growth in the overall energy consumption in the transport sector has been driven by road transport, with the sub-sector accounting for 90% of passenger and 67% of freight movement (MoRTH, 2016). Over the last five years, road transport has witnessed a phenomenal increase in passenger and freight traffic. Passenger road traffic grew at a CAGR of 12.3% between 2010 and 2015, and freight traffic grew at a CAGR of 9.1% during the same period (MoRTH, 2016). Over the same period, the passenger rail traffic grew at a CAGR of 4.1% and rail freight traffic at 2.2% (Ministry of Railways, 2017).

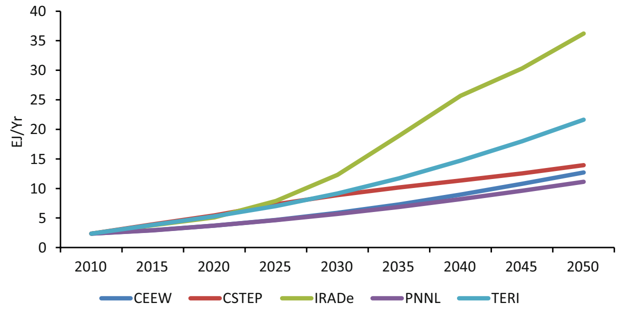

Figure 2: Comparative estimates of energy consumption in the transport sector by 2050

Across the models, it is estimated that the energy consumption for transport increases at a fast pace. Between 2010 and 2030, the total energy consumption increases at a CAGR of 5.1% to 7.9%, and between 2010 and 2050, it increases by 4.2% to 6.7%.

The energy consumption in passenger transport increases at a CAGR of 4.9% to 7.4% by 2030 and 3.8% to 6.9% by 2050 (see Figure 3). In the passenger segment, the growth in energy demand is largely driven by an increase in the share of cars and two-wheelers, which is a consequence of rapid urbanization, rising per capita income, absence of efficient and adequate public transport, and population growth.

Each of the models have varying assumptions regarding occupancy rates, fuel-efficiency levels, and cost constraints based on their own visualizations of technology progress, consumer choices and behaviour, and so on. This results in variations in the resultant energy and emission growth rates across the models. It must be noted that in case of the IRADe model, no efficiency improvements were considered in the Reference scenario, which reflects in the results as higher energy consumption by 2050. On the other hand, the GCAM framework used by both CEEW and PNNL considers ambitious assumptions regarding efficiency improvements across modes even in the Reference scenario. The GCAM framework also incorporates the impact of travel-time savings on mode choice and the total passenger mobility, which translates into lower energy consumption.

In case of freight, the energy consumption grows at a CAGR of 5.1% to 8.5% by 2030 and 4.7% to 6.7% by 2050 as compared to the 2010 levels (see Figure 4).

Across models, the energy consumption in the freight segment is largely driven by road freight, which is almost entirely dominated by diesel vehicles. The models encapsulate a lower share of railways in the freight

[6] *TEDDY estimates are based on information and statistics sourced from government bodies.*

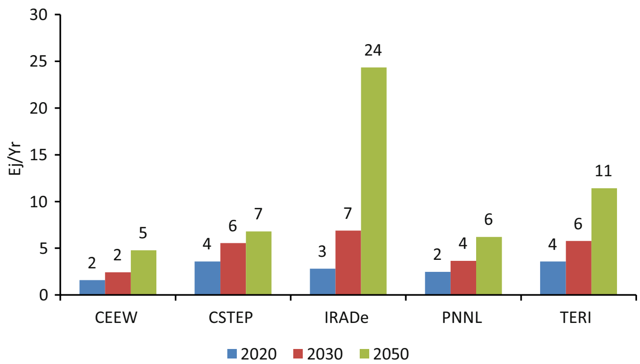

Figure 3: Transport-sector energy consumption: passenger

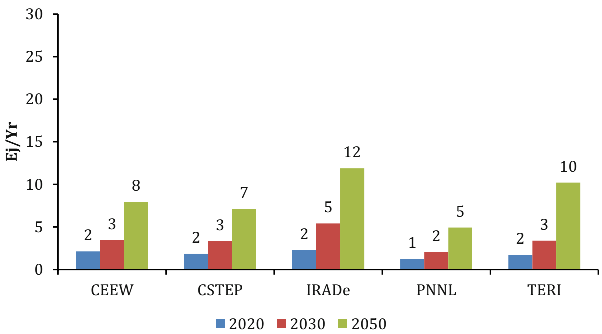

Figure 4: Transport-sector energy consumption: freight

movement, which is consistent with the existing trends of declining share due to inadequate and inconsistent service provision (NTDPC, 2014). Result variation across different models in growth rates of energy consumption stem from the variations in assumptions pertaining to load factors and efficiency rates. The increase in energy demand by the freight segment is higher as compared to the passenger segment because passenger-service demand could be expected to increase with the per capita income only up to a certain level. Beyond this, passengers might derive a negative utility from spending time in travelling. For freight movement, however, this may not be true, and it is more likely to keep on increasing with increased economic activity.

CO_2 Emissions

According to India's First Biennial Update Report (MoEFCC, 2015), the transport sector accounts for 10% of the total CO_2 emissions (from fuel combustion) in the country. Within the land transport sector, road transport accounts for 87% of the CO_2 emissions, followed by railways (4%).

Across the models, the mode share in passenger transport is highly dominated by two-wheelers and LDVs. CO_2 emissions from the passenger transport sector increase from about 104–252 $MtCO_2$ /yr in 2020 to 301–1517 $MtCO_2$ /yr in 2050 (see Figure 5) as a result of the increasing share of LDVs in the total passenger movement, which increases to more than 45% by 2050 across all the models.

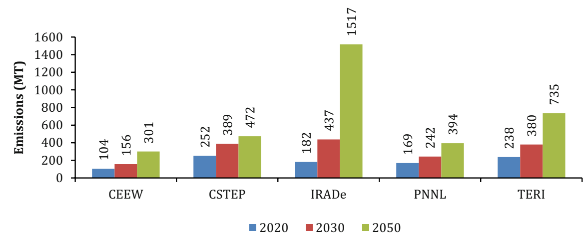

Figure 5: CO_2 emissions from passenger transport

In the freight transport sector, CO_2 emissions increase from 84–166 $MtCO_2$ /yr in 2020 to 490–873 $MtCO_2$ /yr in 2050 (see Figure 6). This is due to the dominance of diesel-run commercial road vehicles[7]. The lack of alternative fuel technologies to substitute emission-intensive High Speed Diesel (HSD) contributes to the increasing emissions from the road freight sector.

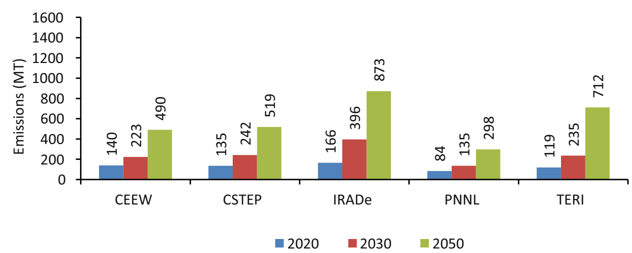

Figure 6: CO_2 emissions from freight transport

Policy Scenarios for Decarbonising the Transport Sector

New Policy Scenario

Based on the comparison of CO_2 emission reduction under each strategy over the Reference scenario, it is observed that till 2030, IRADe and TERI models estimate increased fuel efficiency to be the most effective[8], while PNNL model estimates electrification, CEEW model shows alternative fuels, and CSTEP model results show modal shift to be most effective in reducing CO_2 emissions (Table 2).

A similar trend is observed till 2050 in the New Policy scenario, with the implementation of fuel efficiency representing the highest reduction in emissions for IRADe.

[7]Commercial freight vehicles accounted for 28.25% of the country's diesel consumption, leading to the maximum share in total CO_2 emissions in the freight transport sector.

[8]Under the boundary conditions defined as part of this exercise and without considering modal shifts in freight movement

This high-reduction potential is attributed to both the absence of fuel-efficiency improvements in the Reference scenario and a high share of LDVs by 2050 in IRADe's model. In CSTEP model, modal shift to public transport also provides for a significant reduction in CO_2 emissions, because in the years to follow, a bigger shift occurs towards buses and rail rather than in any other mode of public transport (Table 3).

High Ambitions Scenario

On analysing the impact of policies in the High Ambitions scenario, it is observed that the IRADe and TERI models suggest that increased fuel efficiency can play a key role in reducing CO_2 emissions from the transport sector, while CSTEP's model suggests that modal shift has the maximum potential for decarbonising the transport sector. In the PNNL model, it is observed that with ambitious targets, electrification of the transport sector can lead to significant reduction in the emissions, while CEEW observed that policy on alternative fuels can lead to higher reduction in emissions (Table 4).

By 2050, in the High Ambitions scenario the models once again do not point to a single common strategy. Fuel-efficiency improvement continues to offer significant emission savings by 2050 in the IRADe model, while electrification appears as a promising strategy in CEEW, PNNL, and TERI's model, with modal shift being a favourable policy for CSTEP (Table 5).

Fuel efficiency proves to be the most effective decarbonisation strategy in both policy scenarios by 2050. Electrification can also lead to a significant emission reduction in the transport sector by 2050, if policy targets are achieved as has been set in the High Ambitions scenario. However, it is important to note that electrification, as a policy lever, will be effective in reducing the overall emissions only when there is deep decarbonisation of the power sector.

Further, focus on strategies that reduce the dependence on private motorized vehicles and create demand for public transportation system can also decarbonise the transport sector.

Table 2: Change in CO_2 emissions from land transport: New Policy (2030)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2030 (million tonnes)	630	376	378	833	615
Electrification	-2.5%	-26%	-1.2%	-6.6%	-8.1%
Increased efficiency	-8.0%	-12.9%	-9.3%	-38.8%	-20.6%
Modal shift	-10.9%	-4.8%	-2.1%	-4.5%	-5.8%
Moderating demand	-6.1%	-6.4%	-4.2%	-7.8%	-6.2%
Alternative fuels	-5.0%	-7.6%	-14.8%	-8.3%	-5.9%

Table 3: Change in CO_2 emissions from land transport: New Policy (2050)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2050 (million tonnes)	991	692	791	2389	1446
Electrification	-4%	-28%	-6.2%	-10%	-10%
Increased efficiency	3%	-20.1%	-12.6%	-66%	-17%
Modal shift	-15%	2%	-6.7%	-8%	-11%
Moderating demand	-7%	-8.5%	-9.2%	-15%	-8%
Alternative fuels	-5%	-4.4%	-3.5%	-13%	-5.7%

Table 4: Change in CO_2 emissions: High Ambitions (2030)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2030 (million tonnes)	630	376	378	833	615
Electrification	-6.2%	-24.3%	-5.0%	-11.5%	-18.5%
Increased efficiency	-16.4%	-15.3%	-7.5%	-44.9%	-24.8%
Modal shift	-19.7%	-4.8%	-4.7%	-5.0%	-13.5%
Moderating demand	-9.2%	-9.5%	-4.5%	-9.7%	-9.3%
Alternative fuels	-6.5%	-17%	-27.5%	-12.7%	-8.3%

Table 5: Change in CO_2 emissions: High Ambitions (2050)

	CSTEP	PNNL	CEEW	IRADe	TERI
Reference emissions 2050 (million tonnes)	991	692	791	2389	1446
Electrification	-7%	-24.7%	-12.8%	-21%	-22%
Increased efficiency	-9%	-22.7%	-12.3%	-72%	-21%
Modal shift	-21%	-3.5%	-8%	-9%	-16%
Moderating demand	-10%	-11.4%	-10.6%	-19%	-10%
Alternative fuels	-6%	-13.2%	-8.8%	-16%	-8%

Change in Emission Intensity of GDP

This section presents how the integrated scenario based on a combination of decarbonisation strategies in the transport sector can reduce the CO_2 emissions from the transport sector per unit of GDP (considered as per unit output from the whole economy).

The results of the integrated policy scenario represent the implications that simultaneous implementation of all strategies can have on CO_2 emissions in the transport sector. In the New Policy scenario, till 2030 the models indicate 24%–53% reduction in the transport-related emissions intensity of GDP, while in the High Ambitions scenario, it is in the range of 34%–55%. In 2050, the reduction in transport-related emission intensity of the GDP ranges from 22% to 80% in the New Policy and 30% to 80% in the High Ambitions scenarios (see Table 6).

In the IRADe model, in both medium and long terms, the integrated policy scenarios are compared with a carbon-intensive Reference scenario with a high demand of private vehicles. Hence, the emission-reduction percentage in the longer term is much higher than in other models. In CSTEP and CEEW models, emission reduction is lower in the longer term when compared to the 2030 time frame. This can be attributed to the plateauing rate of fuel-efficiency improvements after 2030.

As compared to 2010, the reduction in transport-related emission intensity of the GDP in the integrated policy lies in the range of 35%–58% and 48%–64% in 2030 in the New Policy and High Ambitions scenarios, respectively. By 2050, the reduction is in the range of 61%–80% in the New Policy and 66%–84% in the High Ambitions scenario (Table 7).

Significant reduction in emission intensities indicated by all the models shows that with the combined strategies considered, the transport sector can play a meaningful and important role in contributing to India's emission- intensity reduction targets.

Corroborative Analysis

- As a decarbonisation strategy, electrification does not provide significant emission-reduction benefits in the short term. This is because the electrification targets are applied only on new-vehicle sales which, in the initial years, account for a minor share of the total passenger-service demand. The emission reductions from electrification are even lower if upstream emissions from power generation are factored in. As per additional analysis by CSTEP[9], the 7% reduction with ambitious electrification targets is limited to 1%, once upstream emissions from power generation are accounted for. Hence, electrification can prove to be an effective strategy in the long term as the power sector gets decarbonised.
- Modal shift in freight from road to rail, as analysed by TERI, reveals that an estimated 30% reduction in CO_2 emissions could be achieved by 2050 in the New Policy scenario. Additionally, in the High Ambitions scenario, the TERI model reflected a 38% reduction in CO_2 emissions by 2050. These results suggest that a modal shift in freight movement towards energy-efficient rail networks can prove to be an important policy lever.
- Considering the transport sector's heavy reliance on fuel consumption, coupled with India's high import dependence on crude oil (83% of the total oil consumption), it is imperative to plan for sectoral policies that

Table 6: Change in transport-sector emission intensity of GDP (tonnes CO_2 /1000 INR)

	2030			2050		
	Reference	New Policy	High Ambitions	Reference	New Policy	High Ambitions
CEEW	1.5	-24%	-34%	1	-22%	-30%
CSTEP	1.9	-26%	-41%	0.9	-22%	-35%
IRADe	2.4	-53%	-55%	2.7	-80%	-80%
PNNL	1.5	-27%	-37%	0.9	-41%	-52%
TERI	2.5	-35%	-47%	1.8	-38%	-46%

can manage fuel and energy demand from the sector in the coming decades and can influence the future carbon emissions (Pal et al. 2015). In this context, the study also estimated that with the implementation of the integrated scenario (New Policy), crude oil imports can be reduced by up to 36 million tonnes/year by 2030. This reduction in oil imports can subsequently lead to substantial savings in the import bill. Table 8 represents the change in energy consumption in the integrated New Policy scenario as compared to the Reference scenario in 2030[10].

Table 7: Change in emission intensity of GDP w.r.t. 2010 Reference scenario (tonnes CO_2 /1000 INR)

		2030		2050	
	Reference	New Policy	High Ambitions	New Policy	High Ambitions
CEEW	2.4	-51%	-57%	-68%	-71%
CSTEP	2.2	-35%	-48%	-67%	-73%
IRADe	2.7	-58%	-60%	-80%	-81%
PNNL	2.6	-58%	-64%	-80%	-84%
TERI	2.8	-42%	-53%	-61%	-66%

Table 8: Final fuel consumption by land transport in the Reference and New Policy scenarios in 2030 (MTOE)

Reference Scenario						Integrated Scenario					
	Diesel		Petrol	CNG	LPG		Diesel		Petrol	CNG	LPG
	Road	Rail					Road	Rail			
CEEW*	107 .73			21.24		CEEW*	102.22			16.67	
CSTEP	141.4	4.0	50.4	5.8	7.6	CSTEP	126.3	2.1	21.6	5.0	4.3
IRADe	207	7	35			IRADe	115	5	16		
TERI	143	5	53	15	0	TERI	101	1	29	9	0
PNNL	112 .4			17.4		PNNL	84.8			9.3	

** Consumption of total fossil liquids*

[9]*The grid emission factor is reduced from 0.82 kg/kWh to only 0.79 kg/kWh after clean energy targets for the power sector are met as per the NDCs in 2030.*

[10]*Refer to Annexure 3 for fuel consumption in different policy strategies (in the New Policy scenario) by 2030.*

Policy Implications

This inter-model study analyzed the implications of various transport-related policies on energy consumption and emissions by 2030 and 2050. The findings indicate that among the decarbonisation policies examined, increasing fuel efficiency and modal shifts seem to have the maximum potential for CO_2 emission reduction.

While the results indicate that fuel efficiency gains can be large, achieving high on-road efficiencies are also contingent on several other factors, such as the congestion levels, quality of infrastructure, maintenance, and so on. Modal shifts towards public transport also indicate significant efficiency gains in the passenger-movement segment and inclusion of modal shifts from road- to rail-based freight, in fact, makes modal shifts the most attractive option in the sector.

The results also indicate that electrification provides emission-reduction benefits in the long run, but these are not substantial if the upstream emissions from the power sector are accounted for. Hence, this clearly indicates that ambitious electrification targets need to be accompanied (or rather preceded) by the power sector's decarbonisation, in order to ensure that large-scale electrification is effective and achieves its purpose.

Although measures to achieve reduction in demand for motorized transport could play a significant role in the longer term, this would require detailed and careful planning for adequate implementation of transit-oriented development (TOD). This should incorporate the development of compact and mixed land-use planning systems, along with the promotion of public and green mobility.

In terms of enhancing the use of alternative fuels, infrastructure requirements for scaling up the supply of biofuels would have to be addressed for harnessing their decarbonisation potential.

Therefore, while electrification, demand management, and alternative fuels should be pursued over time, at this point it appears that early and gradual adoption of the fuel-efficiency standards and decrease in the share of private vehicles (cars and two-wheelers) in favour of increased share of public transport (buses, three-wheelers, and rail) for passenger movement are the most effective and implementable strategies in the transport sector.

Achieving Fuel Efficiency

In April 2017, the average fuel-consumption standards for M1 category[11] vehicles were implemented. As per the new standards, manufacturers are required to meet the new fleet average efficiency of 130g CO_2 /km in 2017 and, subsequently, achieve the efficiency target of 113g CO_2 / km by 2022 (TransportPolicy.net, 2018). The standards are expected to keep approximately 50 million tons of CO_2 out of the atmosphere by 2030 (UNFCCC, 2015). However, for achieving the greater goal of reduced fuel dependence, it is important to apply the efficiency standards to the entire range of all passenger and commercial vehicles and also to ensure that there is strict implementation and compliance of these regulations.

Moreover, it is important to recognize that merely setting up fuel-efficiency standards would not help in achieving reduced fuel consumption unless such measures are complemented with steps to address congestion and the resultant idling of vehicles and to induce lower vehicle utilization over time with better planning of urban centres and more effective public transportation services. Idle running of vehicles, particularly in the freight sector, is also a point of concern in India. It has been estimated that one-fourth of the total fuel is consumed in idling, and almost 34% of the fuel is wasted in empty trips undertaken by trucks (Kumar & Mejia, 2015). It is, therefore, important to address such challenges in order to realize the full benefits of stringent efficiency standards.

Shift from Private to Public Transportation Systems

The share of public transport in passenger travel demand has been decreasing over the years, since the pace of increase in public transport has not been rapid enough to fulfil the mobility demands posed by the already large and growing population, coupled with rapid urbanization. In many cities, there is a complete absence of formal public transportation, while the lack of investment in non-motorized transportation (NMT) and more conventional forms of public transportation, such as buses and railways, has deteriorated the quality of the public transport system in other urban centres. This, coupled with the increasing levels of per capita income, has led to large-scale proliferation of private vehicles. In addition to increased CO_2 emissions, increased penetration of private vehicles exacerbates the negative externalities of air pollution, congestion, and road accidents.

Apart from a modal shift in passenger movement, it is important to identify the potential substitution of road-freight movement by railways and waterways. Freight movement via rail is six times more energy-efficient than by road (TERI, 2014). Despite this, at present almost two-thirds of the freight transport in India is dominated by roads. The key factors responsible for this trend are the high tariff rates of rail freight which have made freight movement by

[11] *A motor vehicle used for carrying passengers, comprising not more than eight seats in addition to the driver's seat.*

road more competitive, the absence of first- and last-mile connectivity in freight networks, and the lack of investment for construction of freight terminals (Planning Commission, 2014; Department of Economic Affairs, 2018).

At present, the Indian transport sector is responsible for 7.5% of country's total CO_2 emissions (MoSPI, 2015). Although this figure seems low, moving forward, the escalation of economic activity, population growth, and urbanization would increase the transport sector's contribution to GHG emissions. Thus, the primary focus of transportation policies should be to reduce the fuel consumption of the existing transportation system. For doing so, it is important to focus on measures that promote improved fuel quality, increased fuel efficiency, a modal shift towards sustainable transportation, and lower vehicular emissions.

Conclusion and the Way Forward

This section presents the key outcomes that have been identified by the teams based on the inter-model comparison of the land-transport-sector policies. Based on the outcomes, the section also provides a roadmap of the possible measures that can be undertaken to further the implementation process.

Overall, the key takeaways from the analysis of different policy scenarios are as follows:

1. The rapidly increasing mobility demand is expected to make the land-transport sector one of the fastest-growing energy sectors, and while the share of current emissions is small, the sector's share of emissions could go higher if significant and appropriate steps are not taken. All the modelling results indicate that growth in mobility is expected to remain robust and, therefore, likely to outpace the benefits of autonomous efficiency improvements that the sector is undergoing due to technical improvements, without additional thrust from government policies and regulations.
2. The contribution of passenger transport to carbon emissions is highly dominated by two-wheelers and LDVs, while road freight transport's carbon emissions are dominated by diesel-run commercial vehicles/HDVs. Aggressively enhancing the shift to alternative modes, both for passenger and freight movement, brings in significant benefits in terms of mitigation besides co-benefits such as decongestion, with reduced pollution and lower cost to the economy in the long run.
3. Increased fuel efficiency and modal shift are the low-hanging fruits with the maximum potential for decarbonising the transport sector as of now. In order to achieve significant levels of decarbonisation in the sector, the expansion of stringent fuel-efficiency standards to all private- and commercial-vehicle segments, and implementation of regulations and incentives to phase out inefficient stocks become inevitable. Further, enhanced investment in public transport and non-motorized infrastructure must play an important role in expanding urban conglomerates.
4. The study's outcomes are reflective of the aspiring policy assumptions that have been considered. In order to fully tap the potential of the policy target, the implementation of norms must be extended to the other vehicle segments by the Ministry of Petroleum and Natural Gas (MoPNG), especially to diesel-driven commercial vehicles in addition to LDVs. As the fuel economy norms (CAFE) for LDVs have already been implemented in 2017 with the target to improve the efficiency of new fleet from 130g CO_2/km in 2017 to 113g CO_2/km by 2022, it is suggested that a more aggressive approach should be adopted in the long run to offset the impact of the growing vehicle fleet.
5. It is also suggested that there should be a mandate to check the efficiencies of the older fleet. MoRTH can be the designated authority to check the emissions from the inefficient vehicular fleet.
6. A labelling programme can also be an effective solution to promote the uptake of fuel-efficient vehicles, which can be supported by incentive-based schemes for consumers.
7. An integrated transport system could play a key role in bringing about a shift towards the public transportation system from private vehicles. Planning and investment in this direction can be made more efficient with the use of intelligent transport systems (ITS), as more information can be collected on people's travel patterns, based on which services like bus rapid transit (BRT) and metro feeder can be encouraged.
8. Apart from the strategy of enforcing stringent fuel-efficiency standards, most of the other strategies need huge investment and large efforts for successful implementation. However, pushing for a modal shift initially in a bigger way and gradually bringing in alternative fuels and greater electrification is more prudent for India at present, given that the Indian grid is still based on a high share of fossil-based electricity and alternative fuels (such as biofuel) face supply-side constraints.
9. There is no single silver bullet which can be proposed for the transport sector, and an integrated multipronged approach towards decarbonising the transport sector is required from the GoI. This is particularly important from the perspective of India's NDC target, because the sector could contribute negatively towards its achievement unless the transport-sector decarbonisation is also pursued simultaneously.
10. Lastly, learning from this exercise was regarding the process of using a multi-model approach, as has been practised in several developed countries. Such an approach can assist in guiding decision makers while laying out policy roadmaps, as it is able to capture the level of uncertainties that different model structures and varying assumptions across scenarios can entail. The idea of collaborative research work is relatively new and at a nascent stage in India and could be helpful in undertaking such studies involving different sectors.

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Annexure 1

CMP

Table 1: Common strategies for inter-model comparisons to be modelled under Reference, New Policy, and High Ambitions scenarios for decarbonising the transport sector

Sl. no.	Decarbonisation Strategies	Strategy description	GoI's current and proposed policies
1	Electrification of transport sector	**Electrification of road transport:** This strategy encompasses the increased penetration/adoption of battery electric vehicles (BEVs) for passenger movement by road.	The government launched the National Electric Mobility Mission Plan (NEMMP) 2020 in 2013 with an ambitious target to promote the sale of 6–7 million hybrid and electric vehicles year-on-year from 2020. With government support, the cumulative sale is expected to increase to ₹15–₹16 million by 2020. In this regard, the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) scheme was introduced by the Department of Heavy Industry to incentivize the purchase of hybrid and electric vehicles (xEV system) through the reduction of upfront purchase price for the buyers. This incentive is applicable to two-wheelers, three-wheelers, four-wheelers, buses, and LCVs.
		Railway electrification: With respect to rail movement, the strategy captures the accelerated electrification of railways for both passenger and freight movement.	Under Mission Electrification, the target is to make Indian Railways greener by electrifying another 24,000 km of rail tracks, thus adding to the existing 28,000 km in the next few years.
2	Increased use of alternative fuels	This strategy encompasses increased use of ethanol-blended gasoline (petrol) for road-based transport vehicles for passenger movement. Further, in order to promote the use of biodiesel, the MoPNG has permitted direct sale of biodiesel (B100) to bulk consumers like Railways, shipping, state road transport corporations, and so on.	A 5% blending target for blending ethanol with gasoline is already mandated by the government. However, even with the current mandate, the country with 10% ethanol blending with gasoline is already mandated by the government in major ethanol-producing states such as UP, Goa, Punjab, Delhi, Haryana, and Karnataka.

Table 1: Common strategies for inter-model comparisons to be modelled under Reference, New Policy, and High Ambitions scenarios for decarbonising the transport sector

3	Increased fuel efficiency for various vehicle categories	This strategy is characterized by the early and increased adoption of increasingly fuel-efficient vehicles in the vehicle fleet through efforts such as the fuel-economy standards and fuel-efficiency labelling efforts. A higher penetration of the newer and more efficient vehicles in the vehicle stock would lead to reduced energy intensities of the transport sector.	A progressive reduction in fuel intensity for all categories of vehicles for passenger and freight The new fuel-efficiency standards for passenger cars are expected to come into force in April 2017. These standards envisage passenger cars to be 10% more fuel- efficient between 2017 and 2021 and 30% more fuel efficient from 2022.
4	Modal shifts	**Increased share of public transport for passenger movement:** This strategy is characterized by increased share of public transport (buses and three-wheelers) for passenger movement.	India had almost 8,000 towns and cities as of 2011. Only 65 of these urban centres have any semblance of a formal public transport system. The coverage of local commuter rail services is available only in the seven metropolitan cities in India: Mumbai, Delhi, Chennai, Kolkata, Bengaluru, Hyderabad, and Pune. India is rapidly urbanizing, with a young population and increasing shares of disposable incomes. The absence of urban public transport systems would continuously lead to a declining share of traffic on public modes, and increased penetration of private vehicles at high economic and environmental costs. The National Urban Transport Policy 2011 focuses on accelerating the usage of public transport.
		Increased share of railways: This strategy is characterized by increased share of railways vis-à-vis road transport for both passenger and freight movement.	The current (2011) share of railways in the total national mobility is: passenger—15% (1,047 BPKM), and freight— 39% (668 BNTKM). This share has been continuously declining. Without any focused action, the share of railways is expected to decline further. The reports of the National Transport Development Policy Committee, 2014, focus on specific policy measures for railways to increase their share in both passenger and freight transport.
5	Moderating the demand for motorized transport	This strategy considers reduction in the motorized passenger-transport demand by promoting integrated and seamless transport, better urban planning (compact cities), and travel-demand management measures such as parking management and congestion pricing.	Better urban planning and various travel-demand management measures such as telecommuting, compressed work week, flexible schedules, and so on, reduces the commuting and travel demands.

Annexure 2

Details of Models Used by the Four Research Agencies

The five models differ in the scope, structure, and exogenous and endogenous variables used in calculation and for projections. The following section describes the model methodology:

Global Change Assessment Model (Used by CEEW and PNNL)

GCAM is a global energy-agriculture-emissions model widely used in climate policy analysis. It is a global (multi-region and multi-sector) dynamic-recursive partial equilibrium model with technology-rich representations of the economy, energy sector, land-use, and water linked to a climate model (AL Brenkert et al., 2003). The model has been deployed in many international modelling-comparison efforts involving integrated assessment models, including those in climate change scenarios (Fawcett et al., 2015), natural gas (McJeon et al., 2014), land-use (Di Vittorio et al., 2014), and transportation (Girod et al., 2013). GCAM's new transportation module was developed in a collaborative effort between PNNL (Kyle and Kim, 2011) and ITS at the University of California, Davis (Mishra, 2013). CEEW has used a unique version of the GCAM model (GCAM-IIM), developed by the Indian Institute of Management (IIM), Ahmedabad.

The transportation services modelled include passenger transport, freight transport, and international shipping with the demand for each service being driven by per capita GDP and population. Each type of service demand is met by a range of competing modes. Changes in modal shares in future periods depend on the relative costs of the different options, modelled using a logit choice formulation. Costs in the passenger sector include the time value of transportation, which tends to drive a shift towards faster modes of transport (LDVs and aviation) as incomes increase. Many of the modes (including LDVs) include competition between different vehicle types, which also uses a logit choice mechanism that is calibrated to base-year shares. For new or emerging technologies (for example, electric or hydrogen vehicles), costs also consider infrastructural constraints and non-economic consumer preferences, and, as such, are especially high in the near-term future time periods. No upper limits for the use of BEVs or fuel cell vehicles (FCVs) were considered in the model. In GCAM, population and income (GDP) are exogenous drivers of passenger-service demand expressed in passenger kilometres travelled (PKT). Further, passenger-service demands by mode are estimated endogenously, based on the total travel costs (USD/PKT) by mode, fuel, technology, and time-cost of travel. The time-cost of travel is a function of the average hourly wage rate of the employed population, mode-specific value of travel time (VTT), and travel speed. Freight-service demand is based on simple functions of population, GDP, and fuel prices in GCAM. The rate of efficiency improvement of each represented vehicle technology is exogenous in GCAM.

GCAM is based on a nested-logit function where the share of technology/mode is determined endogenously based on the average levelized costs of service of each technology/mode in $/PKT (Mishra et al., 2013; Clarke and Edmonds, 1993).

PNNL used GCAM core model version 4.3. However, two important modifications were made to that model. First, PNNL changed the assumptions for the total energy used by passenger- and freight-road transport in the base year (2010). The core GCAM model uses energy data from the International Energy Agency (IEA). The IEA does not split energy in transportation by passenger and freight; instead, the assumptions from the University of California (UCD), Davis, are used. For this exercise, PNNL has changed the default assumptions from the UCD. PNNL has changed the allocation of fuels between transportation modes in India based on PPAC estimation (PPAC, 2012). As a result, the total energy used by road transportation in 2010 is the same as in PNNL and CEEW. However, the split between passenger and freight is different. Secondly, PNNL has added electric three-wheelers to the model. The assumption on distance travelled is the same as for liquid-fuelled three-wheelers, while cost assumptions for electric three-wheelers are calculated as the average between electric two-wheelers and electric cars.

India Multi-Region TIMES (Used by CSTEP)

CSTEP has developed IMRT model based on the MARKAL-EFOM suite, or TIMES (Loulou, 2005; Byravan, 2017). The IMRT is a bottom-up energy system model that has been used in studies to examine several combinations of technology and policy options based on constrained optimization. CSTEP developed IMRT model in order to gain deeper systemic understanding of linkages amongst energy subsystems, economic drivers, and technology and policy choices in end-use sectors like transport. The transport module for the IMRT model is a spreadsheet-based accounting model, which is soft-linked to the energy flow and emission trajectories of the power-sector module to achieve consistency in emission trajectories in decarbonisation scenarios in the current study. The structure of the IMRT transport module is based on the activity–structure¬–intensity–fuel carbon (ASIF) identity methodology developed by the IEA (IEA, 2013).

For consistency with the CSTEP's IMRT model, the transport module was set up to yield results on variables such as service or activity demand, final energy demand, primary energy requirement, and emissions. The final energy demand is an exogenous input to the IMRT's power-demand module. Data on activity demand is scarce in India. Activity demand for passenger in the modelling time horizon of 2010–2050 is modelled on the basis of calculated historic GDP elasticity of service demand. Deflators are used to reflect a slowing down of growth in the latter time period. Further, secondary data on the transport-sector activity share (passenger and freight), share of different modes (road and rail), load factors, and road-based passenger and freight vehicle shares, and fuel efficiency by technology type (GoI, India Energy Security Scenarios, 2015), was used. Fuel-emission factors (CO_2) (INCAA, 2010) and technology-wise PM2.5 emission factors (ICCT, 2015) were used to set up the reference energy system for the transport sector. Base year energy consumption for 2010 and 2015 was calibrated against fuel-wise totals reflected in the government estimation of retail fuel consumption for the transport sector (PPAC, 2012).

Various strategies such as electrification, improved efficiency and other were modelled by varying the exogenous inputs to the model. In electrification, percentage sales targets were applied on cumulative additional service activity for the segment in question in the business as usual scenario in a given time period. The remaining service activity was distributed proportionately to other sub-modes such that aggregate service demand totals remain consistent.

The transport module hence allows the user to create plausible scenarios to explore the systemic impacts of various technological, economic and policy choices. This modelling is helpful to evaluate policies to minimise fuel imports, mitigate environmental externalities and plan infrastructure requirements for the ever-expanding transport sector.

IRADe's IAM

IRADe-IAM model is a multi-sectoral, inter-temporal dynamic optimization model that is bottom-up as it includes alternative technology options, and top-down as it covers the whole macroeconomy (Pradhan, 2013). It uses the social accounting matrix (SAM) for 2007–08 (Parikh and Ghosh, 2009) to represent the whole economy and the inter-sectoral linkages. The SAM used in the model is aggregated to 28 commodities and 46 production activities. The model is set up in an activity-analysis framework and is solved as a linear-programming problem simultaneously over a 50-year time horizon.

The transport sector is represented in the model by railways, road transport, water transport, air transport, and auxiliary-transport-related activities. The road-transport-sector services are provided by three activities (technologies): a) conventional technology based on petroleum products, b) electricity-based transportation, and c) gas-based transportation. The intermediate demand (input demand in the input–output [I-O] framework) for the road-transport sector by other economic sectors (in its production process) corresponds to freight-transport demand. The consumption demand for road-transport output by private households and the government corresponds to the passenger-transport demand.

The transport-sector passenger and freight service demand was estimated in two steps. In the first step, the passenger demand (in pkm) and freight demand (in tkm) are related to the household-consumption expenditure on road transport and the intermediate demand for the road- transport sector, respectively, in the base year of the SAM. The household expenditure on road transport is disaggregated into mode-wise expenditure using the National Sample Survey data. In the second step, the year-on-year rate of growth of consumer expenditure on each mode of road transport is used to project the passenger demand (in pkm). The year-on-year increase in the intermediate demand for the road-transport sector is used to project the freight transport (in TKM) for the subsequent years.

TERI's MARKAL Model

TERI's India MARKAL model has been developed over the past two decades and used for several studies undertaken by TERI in the past. These include 'Co-benefits of Low-Carbon Pathways for India' (TERI, 2018), 'Energy Efficiency Potential in India' (TERI, 2018), 'Climate Change Risks and Preparedness for Oil and Gas Sector in India' (TERI, 2018), 'Air Pollutant Emissions Scenario for India' (Sharma and Kumar, 2016), 'Energy Security Outlook' (TERI, 2015), 'Pathways to Deep Decarbonisation' (Sachs et al., 2014) and 'The Energy Report: India 100% Renewable Energy by 2030' (TERI, 2013). Outputs from the model have also been used to develop India's INDC document.

MARKAL (MARket ALlocation) is a bottom-up, dynamic, linear-programming model that depicts both the energy-supply and demand sides of the energy system. The MARKAL family of models is unique, with applications in a wide variety of settings and global technical support from the international research community. MARKAL interconnects the conversion and consumption of energy carriers. This user-defined network includes all energy carriers involved in primary supplies, conversion and processing (for example, power plants, refineries, and so on), and end-use demand for energy services that may be disaggregated by sector and by specific functions within a sector. The optimization routine used in the model's solution selects from each of the sources, energy carriers, and transformation technologies to produce the least-cost solution, subject to a variety of constraints. The user defines technology costs, technical characteristics (for example, conversion efficiencies), and energy-service demands.

The model database is set up over a 50-year period, extending from 2001–2051 at five-yearly intervals, originally intended to coincide with GoI's Five-Year Plans. In the model, the Indian energy sector is disaggregated into five major energy-consuming sectors, namely, agriculture, commercial, industry, residential, and transport sectors. Each of these sectors is further disaggregated to reflect the sectoral end-use demands. The model is driven by the demands on the end-use side, which are exogenously determined by excel-based econometric models.

On the supply side, the model considers the various energy resources available both domestically and from abroad for meeting the various end-use demands. These include both conventional energy sources (coal, oil, natural gas, and nuclear) as well as renewable energy sources (hydro, wind, solar, biomass, and others). The availability of each of these fuels is represented by constraints on the supply side.

The relative energy prices of various forms and source of fuels play an integral role in capturing inter-fuel and inter-factor substitution within the model. Furthermore, various conversion and process technologies characterized by their respective investment costs, O&M costs, technical efficiency, life, and so on that meet the sectoral end-use demands are also incorporated in the model.

India-specific technology costs (capital costs and O&M costs) for various technologies included in the database have been obtained from various sources. Wherever India-specific costs are not available, international figures are used. Future cost reductions in emerging technologies are assumed based on an understanding of how these technologies are expected to develop.

The database in its current form incorporates 47 end-uses spanning nearly 350 technologies. The current database differs from the previous databases in terms of the driver of the model, like the GDP and constituent parameters designed specifically to meet the requirements of CD-LINKS scenarios.

Annexure 3

Final Fuel Consumption by Alternate Scenarios (MTOE)

Reference Scenario (2010)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	49.10				
CSTEP	39.30	1.78	12.65	0.62	1.58
IRADe	49.91	1.63	7.87		
TERI	42.03	1.94	12.92	1.78	0.17
PNNL*	49.0			2.3	

Electrification (New Policy 2030)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	114.67			21.14	
CSTEP	140.97	2.66	46.89	5.76	7.49
IRADe	199.21	4.73	29.86		
TERI	136.04	4.44	44.01	13.12	0.32
PNNL*	85.0			10.4	

Increased Fuel Efficiency (New Policy 2030)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	106.71			17.46	
CSTEP	131.75	3.66	43.70	5.78	7.55
IRADe	120.86	4.87	20.67		
TERI	111.55	4.69	43.65	10.74	0.47
PNNL*	99.2			13.4	

Moderating Demand (New Policy 2030)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	111.25			20.30	
CSTEP	134.73	3.99	45.34	5.20	6.80
IRADe	195.27	4.79	30.86		
TERI	136.12	4.98	47.27	13.41	0.42
PNNL*	105.4			16.1	

Annexure 3

Final Fuel Consumption by Alternate Scenarios (MTOE)

Modal Shift (New Policy 2030)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	113.08			21.23	
CSTEP	141.79	4.15	28.75	5.63	4.83
IRADe	201.42	4.96	32.96		
TERI	145.65	5.44	36.69	14.24	0.51
PNNL*	101.3			21.0	

Alternative Fuels (New Policy 2030)						
	Diesel		Petrol	Biofuel	CNG	LPG
	Road	Rail				
CEEW*	107.57			7.91	21.65	
CSTEP	134.29	3.79	45.34		5.78	7.55
IRADe	201.08	4.74	31.44			
TERI	142.61	5.32	52.52	12.65	14.90	0.47
PNNL*	102.7				17.7	

Integrated Scenario (New Policy 2030)					
	Diesel		Petrol	CNG	LPG
	Road	Rail			
CEEW*	102.22			16.67	
CSTEP	126.3	2.1	21.6	5.0	4.3
IRADe	115	5	16		
TERI	101	1	29	9	0
PNNL*	84.8			9.3	

** Consumption of total fossil liquids*

Annexure 4

Advisory Board for SGWG: Transport		
1	R P Gupta, Additional Secretary	NITI Aayog
2	Anil Kumar Jain, Additional Secretary	Ministry of Environment, Forest and Climate Change
3	D N Prasad, Adviser (P)	Ministry of Coal
4	Geeta Singh Rathore, Director (EFD)	Ministry of Statistics and Programme Implementation
5	Prahalad Parihar, Chief Engineer (CEA)	Ministry of Power
6	Saurabh Diddi, Director, BEE	Ministry of Power
7	A Duraisamy, Scientist	Ministry of Environment, Forest and Climate Change
8	Sanjay Sudhir, JS (IC)	Ministry of Petroleum and Natural Gas
9	Dilip Nigam, Adviser	Ministry of New and Renewable Energy
10	Abhay Damle, JS	Ministry of Road Transport and Highways
11	Sandeep Srivastava, Director (Infra)	Ministry of Railways
12	Venkatramana R Hegde, Director	Ministry of Civil Aviation
13	Mukund Sinha , OSD	Ministry of Urban Development
14	K Guite, Adviser	Transport Research Wing, Ministry of Road Transport and Highways
15	Manoj Singh, Adviser	Transport, NITI Aayog
16	Rajnath Ram, Joint Adviser	Energy and IC, NITI Aayog
17	Shyam Gupta	Petroleum Planning and Analysis Cell

Glossary

Service demand	Representation unit travel activity (passenger or freight)
Biofuels	Fuels derived from biomass or waste feedstock (including ethanol and biodiesel)
Decarbonisation	Reduction or removal of CO_2 from energy sources
Service Intensity of GDP	Passenger- and freight-transport service demand per unit of the national GDP
Energy Intensity of Service	Energy consumption per unit of transport-service demand
Emission Intensity of GDP	CO_2 emissions per unit of the national GDP
Emission Intensity of Energy	CO_2 emissions per unit of the energy consumed
GDP Elasticity of Service Demand	Variation in the transport-service demand with respect to India's GDP growth

About the Authors

The Center for Study of Science, Technology and Policy (CSTEP) is a private, not-for-profit research organization working in the fields of energy, infrastructure, security studies, materials, climate studies, and governance. For more information, visit www.cstep.in.

The Council on Energy, Environment and Water (CEEW) is a not-for-profit policy research institution operating in areas like energy access, renewables, the power sector, industrial sustainability and competitiveness, low-carbon pathways, risks and adaptation technology, and finance and trade. For more information, visit www.ceew.in.

Integrated Research for Action and Development (IRADe) is an independent not-for-profit advanced research institute working in areas like energy and power systems, sustainable urban development, climate change and environment, poverty alleviation and gender, agriculture and food security. For more information, visit www.irade.org.

The Pacific Northwest National Laboratory (PNNL) is one of the national laboratories of the US Department of Energy (DOE) , managed by the DOE's Office of Science. It deals in areas pertaining to energy, environment, and national security. For more information, visit www.pnnl.gov.

The Energy and Resources Institute (TERI) is a not-for-profit research institute that conducts research in the fields of climate change, clean and renewable energy, energy and resource efficiency, water, waste and environment, sustainable cities, green buildings, low-carbon mobility solutions, clean air, health and nutrition. For more information, visit www.teriin.org.

About Shakti Sustainable Energy Foundation

The Shakti Sustainable Energy Foundation works to facilitate India's transition to a cleaner energy future by aiding the design and implementation of policies that promote clean power, energy efficiency, sustainable transport, climate policy, and clean energy finance.