Win-Win Transportation Strategies for India: Linking Air Pollution and Climate Mitigation

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Abstract

This article analyzes road transport in India to explore linkages between air pollution and climate change policies in the transportation sector. Five teams modeled five policy scenarios – fuel efficiency, electrification, alternative fuels, modal shifts, and moderation in transport demand – to explore which policy brings the largest synergetic effects in reducing carbon dioxide (CO_2) and particulate matter ($PM_{2.5}$) emissions. The teams also modeled the comprehensive scenario which included policy measures from individual scenarios. The paper concludes that all of the measures provide strong co-benefits in reducing air pollutants and CO_2 emissions. The modeling results show that the increased energy efficiency of passenger and freight vehicles has the largest potential for reducing both CO_2 and $PM_{2.5}$ emissions. It is possible to reach an even larger reduction of air pollutants and CO_2 emissions by combining several policy measures in the comprehensive scenario.

1. Introduction

While climate change is widely recognized as a serious global threat, it is also true that addressing climate change is seldom a top priority for policy makers. Energy access, jobs and economic growth, energy security, air pollution, and other issues/goals demand the immediate attention of policy makers, leaving climate mitigation far down on the list. Climate change mitigation will therefore be most successful if it can support these other goals or at least not conflict with them. Air pollution and associated health impacts are two of the most important issues many countries are facing today.

As India looks at both its near-term climate mitigation actions and its long-term climate mitigation strategy, it has an opportunity to hone those actions and strategies to best align them with air pollution and broader goals surrounding the reduction of emissions from its energy system. Air pollution is a particularly important policy imperative in India. In 2020, India was home to 15 of the 20 most polluted cities in the world, as measured in terms of particulate matter ($PM_{2.5}$) concentrations [1]. The Government of India set the national target to achieve a 20-30% reduction of particulate matter emission concentrations by 2024 [2].

India, like many other countries, is continually taking actions and building strategies to further its agenda for growth and development. In its first Nationally Determined Contributions under the Paris Agreement, India pledged to reduce the emissions intensity of the national economy by 33-35% by 2030 below 2005 levels [3]. India has not yet submitted updated 2030 targets to the United Nations Framework Convention on Climate Change (UNFCCC). At the 26th United Nations Climate Change Conference in Glasgow, the Government of India announced its net-zero target for the first time. India pledged to achieve net-zero carbon emissions by 2070. India would need to develop and implement sectoral policies to achieve this goal.

Climate mitigation can be a foundation for India's long-term growth and development strategy if it can support other areas of national interest, such as air pollution and modernization of the energy system. Therefore, a critical question is: which mitigation actions and strategies provide the most mitigation benefit to air pollution improvements and emissions reductions? Are some policy measures more synergistic than others?

Transportation is an important source of urban air pollution in India. Though the number of vehicles per capita in India is still very low compared to advanced countries, the number of registered vehicles increases about 10% per year [4]. Transport currently accounts for a relatively small share of total final energy consumption which is below the level of many advanced countries. However, energy consumption by transport has more than doubled in the past ten years and more than tripled since 2000 [5]. As the fifth largest vehicle-producing country in the world, India can set its own emission standards and persistently implements more stringent requirements [6, 7]. The most important policy driver for emission reductions was the introduction of the most advanced emissions standards for passenger and freight vehicles (the Bharat VI system which is identical to the final European Euro 6 standard for passenger vehicles and Euro VI standard for freight vehicles). Overall, the role of vehicles in energy consumption and emissions will increase in the future driven by increasing service demand

In this study, we bring together five leading models of the Indian energy sector and apply them to understand the synergies between transportation emission mitigation policies and air pollution. Our goal is to understand which transportation policies can have a powerful effect on both. We also aim to understand where synergies might or might not exist between policies. We explored five main categories of actions and strategies: fuel efficiency, electrification, alternative fuels, modal shifts, and moderation in transport demand. In this article, we analyzed energy demand and emission trends from passenger vehicles (two-wheelers, three-wheelers, passenger cars, and buses) and freight transport (light heavy-duty trucks, medium heavy-duty trucks, and heavy heavy-duty trucks).

The inclusion of multiple models and modeling teams is an important aspect of this study. The teams modeled a common set of scenarios and harmonized assumptions on GDP and population growth. No model can infallibly predict the future, but by looking across multiple models and multiple perspectives, we can gain confidence in some insights, increase our skepticism about others, and identify new areas for research. We did not seek definitive answers in this paper, only a clearer picture of robust strategies that can inform India's long-term mitigation strategy and, most importantly, its broader strategy for growth and development.

A major link between air pollution and climate change is through emissions of short-lived climate forcers. Actions to reduce GHG emissions also bring reductions in air pollutants, including PM emissions.

The synergy is strong between a modernized transportation system, climate mitigation, and air pollution. Indeed, the results point to the possibility, as has been demonstrated in other studies (e.g., [8]), that the modernization associated with mitigation may be the most effective strategy to meet the highest health standards for $PM_{2.5}$.

The rest of this paper is organized as follows: Section 2 provides an overview of the methodology used in this paper. Section 3 then presents and discusses the results of the reference and policy scenarios. Section 4 concludes the paper by drawing broader insights and pointing to continuing analytical needs to support the synergy between climate mitigation and India's growth and development agenda.

2. Methodology

2.1. Objectives of the study

The overarching goal of the paper is to compare emission reductions potentials of several policies for passenger and freight road transport in India. Four leading Indian modeling teams and one US-based research organization developed their reference scenarios for road transport and five policy scenarios with harmonized assumptions to look for synergies between reductions of air pollutants ($PM_{2.5}$ emissions) and climate change forcers (CO_2 emissions).

2.2. Models used in this study

The five teams include the Center for Study of Science, Technology and Policy (CSTEP), Integrated Research and Action for Development (IRADe), The Energy and Resources Institute (TERI), Council on Energy, Environment, and Water (CEEW), and US-based Pacific Northwest National Laboratory (PNNL).

Both PNNL and CEEW used the Global Change Analysis Model (GCAM), developed by PNNL's Joint Global Change Research Institute. 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 [9]. CSTEP used the India Multi-Region TIMES (IMRT) model, which is a bottom-up model based on the MARKAL-EFOM suite of models [10, 11]. 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 decarbonization scenarios examined in the current study. For this study, TERI used the TERI-MARKAL model, which is a dynamic linear-programming 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, which is a multi-sectoral, intertemporal dynamic optimization model [12]. Additional details about the models used by each of the teams can be found in our previous study [13].

2.3. Scenarios explored in this study

In this study, we explored five main scenarios of actions and strategies: efficiency, electrification, alternative fuels, modal shift, and moderation in transport demand. Each of these scenarios is described by a set of assumptions that modeling teams deployed into their models (Table 1). We should note that only the increased-efficiency and alternative fuel scenarios include measures for both passenger and freight vehicles. All other individual scenarios include measures to reduce energy consumption and emissions from passenger vehicles only. As a result, as expected, the effect of, for example, the increased-efficiency scenario implementation would be larger than in other individual scenarios.

Table 1: Overview of policy scenarios

Scenario	Policy
Increased efficiency	Increase fuel efficiency of passenger and freight vehicles
Electrification of road transport	Electrification of 2W, 3W, cars, and buses
Modal shift	Switching from private passenger vehicles to public transportations
Reduced travel demand	Reduction of travel demand relative to the reference scenario
Alternative fuels	Deployment of biofuels for road vehicles
Comprehensive scenario	All assumptions from individual policy scenarios

In order to enable a comparison of policy scenarios across the models, the teams harmonized some key assumptions. Under a common modeling protocol, 2010 was chosen as a base year for the modeling exercise as the inventory of GHG emissions for India was available for this year at the time of modeling [14]. The protocol also includes common assumptions about socio-economic drivers, such as GDP and population growth. In IRADe's model, GDP is endogenously determined based on certain inherent assumptions for various macroeconomic parameters such as savings rate, labor productivity, and other indicators. The other four models used exogenous GDP growth trajectories based on NITI Aayog's India Energy Security Scenarios (See Supplement Table S1). The population projections across all five models were based on the World Population Prospects [15], with India's population projected to grow at a rate of 0.5% per year till 2050 from 1.3 billion in 2015.

The parameters for scenarios are based on extensive discussion between the teams and with representatives of the Government of India about what policies might be realistic. Equally important, the results provided in the next section can be normalized to provide a sense of the degree to which synergies between mitigation and air pollution exist regardless of stringency. Supplement Table S2 provides information about the quantitative goals of each policy scenario.

3. Results

3.1. Results from the reference scenario

All models show substantial growth in energy consumption by both passenger and freight transport (Figure 1). Passenger transport energy consumption is projected to grow 3.4-5.8% per year from 2010 to 2050 in all the models except IRADe's, where the growth rate is 7.7% per year. In the passenger segment, the energy consumption growth is fueled by an increase in the share of personal vehicles. Energy consumption by freight transport increases by 3.4-5.7% per year. Supplement Figure S2 shows additional detail on energy consumption by mode.

Without new policies to constrain emissions between 2010 and 2050, CO_2 emissions from passenger transport are projected to follow the energy consumption trends. The results of the reference scenarios in this study are consistent with the results described in our previous work [13] (See Supplement for details).

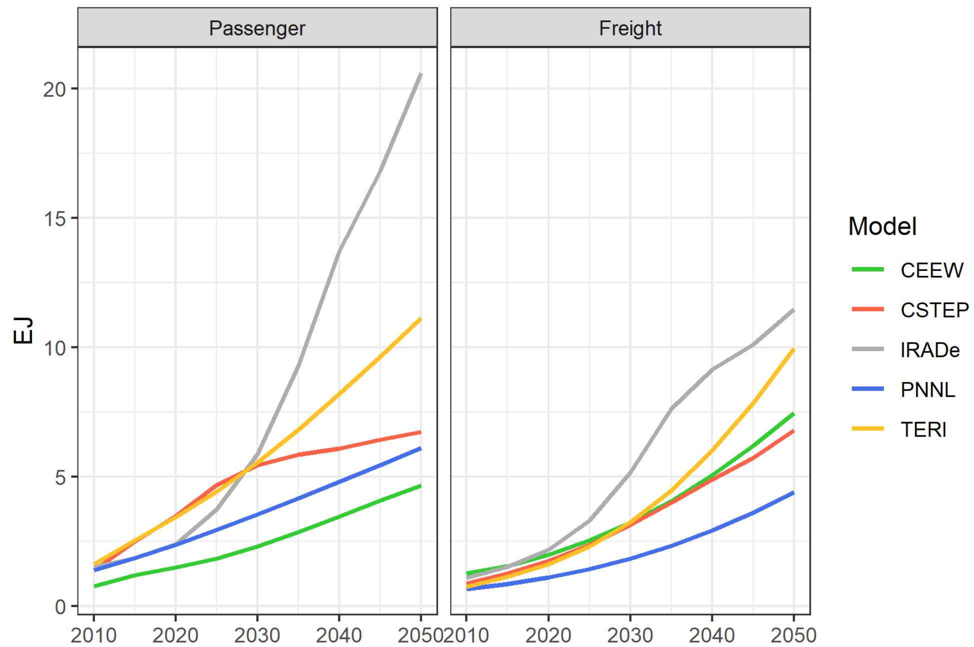

Fig. 1. Energy consumption by type of road transport in the reference scenario.

We also estimated $PM_{2.5}$ emissions from road vehicles to assess the importance of emission control policies. We used two Bharat emission standards that define the legal limits on the amount of air pollutants, to show how more stringent emission standards impact $PM_{2.5}$ emissions.

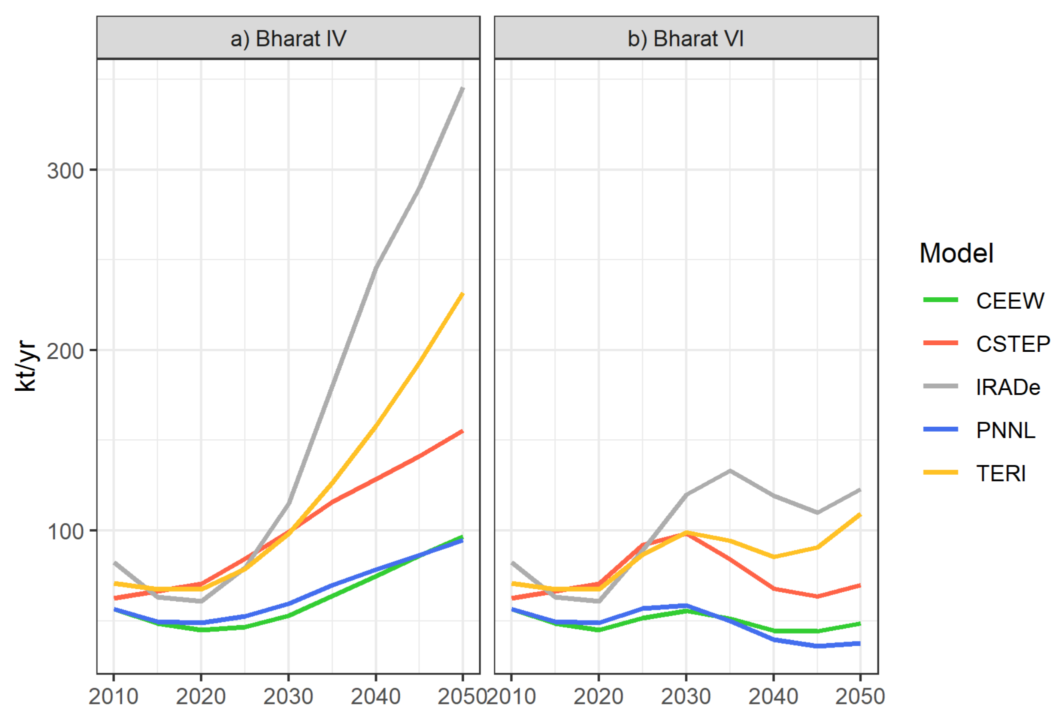

Fig. 2. Transportation $PM_{2.5}$ emissions in the reference scenario.

Without new emissions standards after 2020 (Figure 2a), $PM_{2.5}$ emissions start to grow because of increased service demand. On the other hand, emissions factors in the new Bharat standards are much lower, so PM emissions remain low (Figure 2b). Emissions increase after 2040 or 2045 as the fleet meets the Bharat VI standard, but service demand continues to grow. The difference in PM emissions with Bharat IV and Bharat VI shows the importance of more stringent emissions standards, as well as enforcement of this transportation policy. For the remaining part of the paper, we use the estimates of $PM_{2.5}$ emissions calculated with the Bharat VI standards, which are gradually penetrating the transportation fleet from 2020 to 2050.

The models used in this study differ in terms of how they approach the modeling of the transportations sector. To further analyze trends in emissions from passenger and freight transport, we looked at changes in transportation services, energy consumption, CO_2 emissions, and GDP in the reference scenario across the models. The growth in the transport sector's emissions per unit of GDP can be explained by the change in the emissions intensity of transport energy (CO_2 emissions per unit of energy, tCO_2/EJ), the energy intensity of transport (final energy per unit of service demand, EJ/pkm or EJ/tkm) and the service intensity of GDP (passenger/freight service per unit of GDP). This simplified representation of the Kaya identity could be useful to understand the drivers behind CO_2 emissions growth. Supplement Table S3 presents annual changes in these intensities for both passenger and freight transport sectors.

Several conclusions can be drawn from this analysis. First, while emission intensity for passenger transport decreases across all models, in freight transport CEEW and PNNL models show a decline in emissions intensity. CSTEP, IRADe and TERI did not have built-in improvements in emission intensity for trucks; in these models, trucks emit the same amount of CO_2 for each ton-kilometer in 2050 as they did in 2010. Second, all the models implied some reduction of the energy intensity of service for passenger transport, while only two models show some reductions in the energy intensity of freight service (CEEW and IRADe). In other words, in these models, trucks use a constant amount of energy for each ton-kilometer throughout 2010-2050. Finally, all models show some increase of the service intensity of GDP for passenger transport, and all models but one (TERI) have improvements in the service intensity of GDP for freight transport. These insights can help in understanding the model results of service, energy consumption, and emissions for passenger and freight road transport in India.

3.2. Strong co-benefits of reducing CO_2 and $PM_{2.5}$ emissions: results from policy scenarios

The teams modeled five policy scenarios to estimate the effects of policy measures on energy consumption and emissions. We also modeled the comprehensive scenario, which includes all measures from the individual scenarios.

Among all policy scenarios, the implementation of the efficiency scenario has the largest potential for the reduction of energy consumption. Energy consumption in 2050 decreases between 9% and 23% with the exception of the IRADe model, where total energy consumption decreases by 48% compared to the reference scenario. In the comprehensive scenario, energy consumption decreases between 26% in CEEW and 54% in IRADe compared to the reference.

Trends in CO_2 emissions mostly follow the trends in energy consumption (Figure 3). The results show that the implementation of the increased efficiency scenario followed by electrification provides the highest potential for CO_2 emission reductions. CO_2 emissions in the electrification scenario decrease the most in models where the penetration of electric vehicles is the largest (IRADe, PNNL and TERI). Diminishing CO_2 emission factors from the power sector also contribute to increased savings from electrification (Note: CEEW did not model the electrification scenario). The moderating travel scenario shows some emission reductions, which are proportional to a reduction in service demand. Emissions reduction in the modal shift scenario is the largest in PNNL because of a large penetration of buses with relatively moderate growth of passenger service by three-wheelers. Blending biofuel in the alternative fuel scenario resulted in a marginal change in carbon emissions.

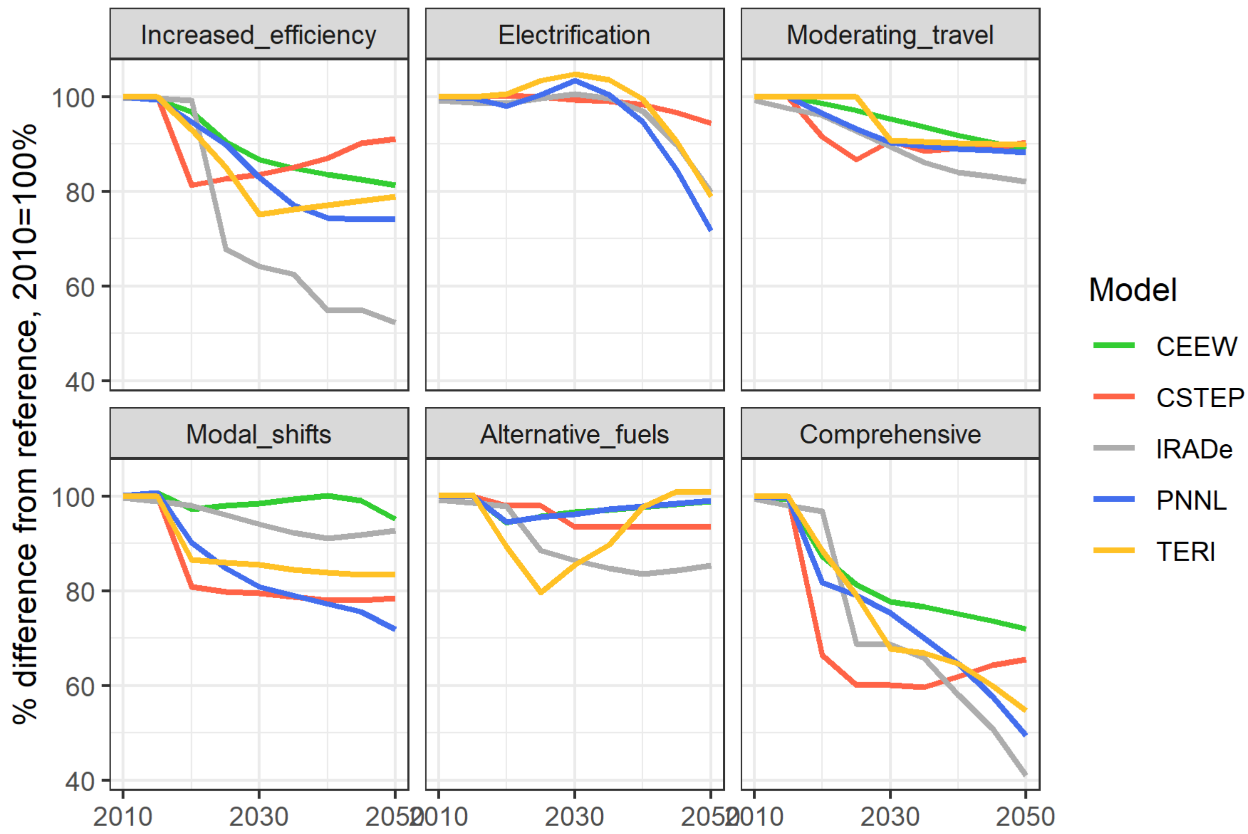

Fig. 3. CO_2 emission reductions (% reduction from the reference scenario).

The comprehensive scenario combines all policy measures from all individual scenarios. In 2030, CO_2 emissions in the comprehensive scenario decrease between 19% and 46% compared to the reference scenario. With the full implementation of policies after 2030 (especially electrification), in 2050, CO_2 emissions decrease by 28-51% in four models, while this reduction is 59% in IRADe's model (Figure 3).

We also analyzed the effect of the implementation of various policies on PM emissions (Figure 4).

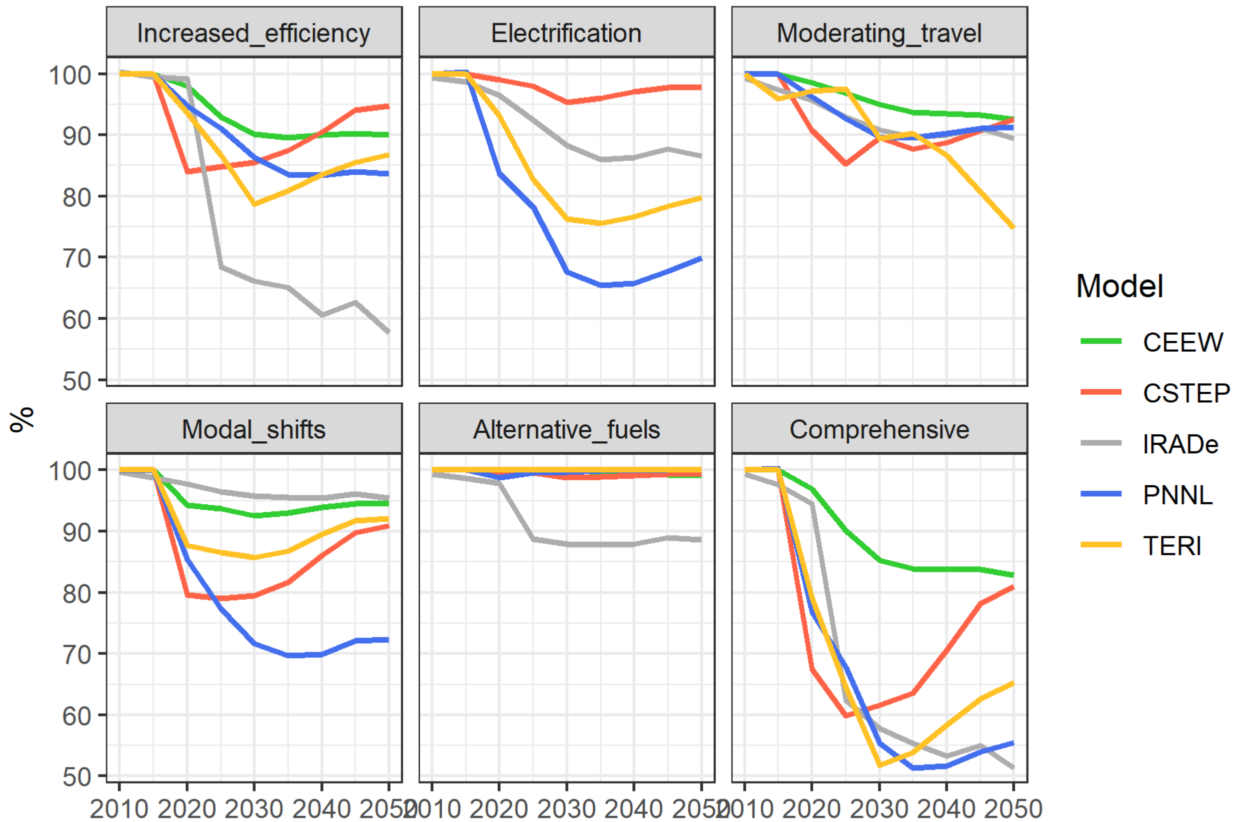

Fig. 4. PM emission reductions (% reduction from the reference scenario).

Among all policy scenarios, the electrification scenario brings the largest benefits in terms of $PM_{2.5}$ emission reductions. As passenger transport is concentrated in large cities, electrification of passenger vehicles sharply reduces $PM_{2.5}$ emissions. Similarly, the promotion of buses instead of three-wheelers reduces $PM_{2.5}$ emissions in the modal shifts scenario. The increased efficiency and moderating travel scenarios demonstrate lower reductions in air pollutants. Finally, the alternative fuel scenario shows almost no reductions in $PM_{2.5}$ emissions since gasoline and diesel are simply substituted with bioethanol and biodiesel (where the emission factors are the same).

To assess synergies between emissions and air pollutant reductions, we compared reductions of CO_2 and $PM_{2.5}$ for five policy scenarios and the comprehensive one (Figure 5).

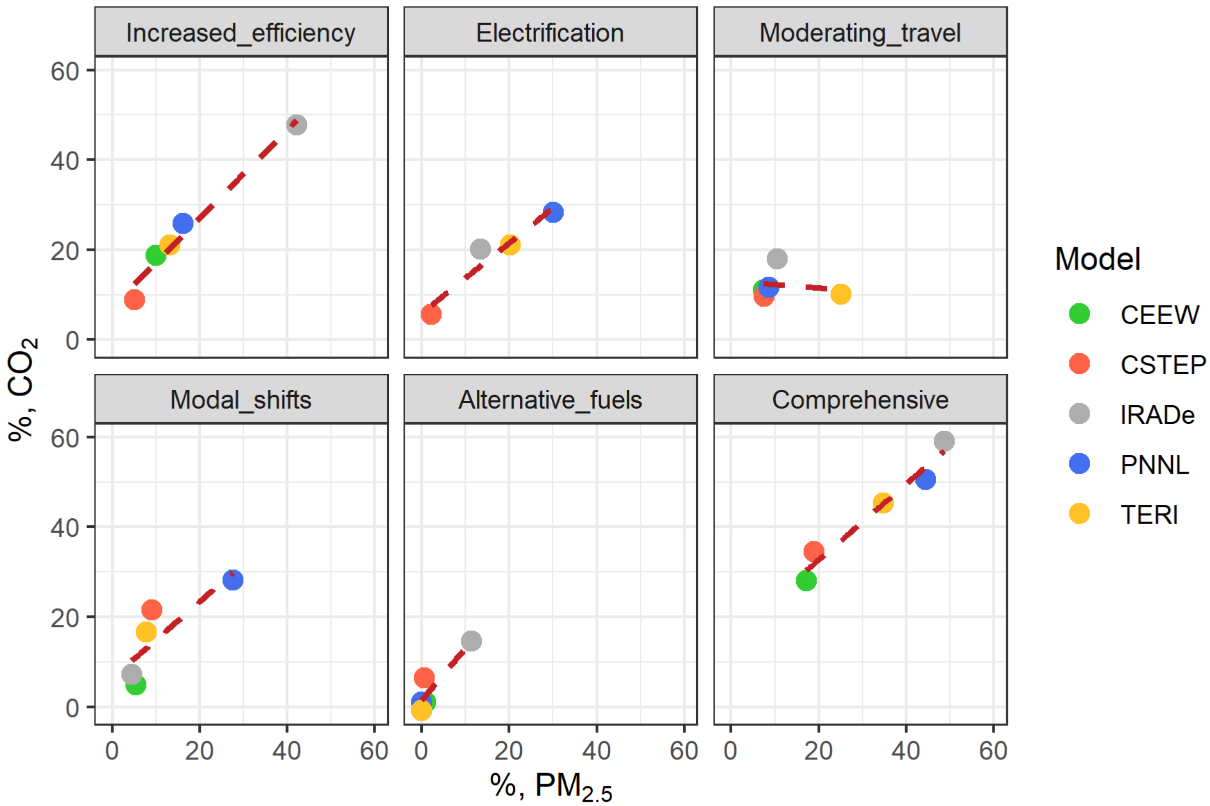

Fig. 5. $PM_{2.5}$ and CO_2 reductions in 2050 (Percent reduction from the reference scenario in 2050).

Several conclusions arise for the analysis of CO_2 and $PM_{2.5}$ emissions reductions:

- The overarching conclusion from this study is that despite very different models, different scenarios, and different starting points in implementing policies, all measures bring co-benefits in reducing $PM_{2.5}$ and CO_2 emissions. The results show strong consistencies in emissions reductions.
- Increased efficiency of passenger and freight transportation is a universal way to reduce emissions and air pollutants. This study found that the increased efficiency scenario has the largest synergy effect in reducing CO_2 and $PM_{2.5}$ emissions among all modeled individual scenarios. If vehicles consume less fuel to move passengers or cargo, co-benefits would be the strongest, especially in large cities.
- Electrification of passenger vehicles eliminates $PM_{2.5}$ emissions and moves end-of-pipe CO_2 emissions from vehicles to power plants. Decarbonization of the power grid would be critical to fully appreciate the clean air due to the penetration of electric vehicles. The results from the TERI and PNNL models, where the penetration of electric vehicles is the largest, clearly show that if the power sector remains carbon-intense between 2020 and 2040, CO_2 emissions will increase with the growth of the electric fleet. After 2040, as the power sector decarbonizes, CO_2 emissions from transportation will decrease.
- Moderating travel can potentially reduce both CO_2 and $PM_{2.5}$ emissions from passenger transport, though the implementation of policy measures to reduce passenger service demand could be challenging and goes beyond the transportation sector.

- Modal shifts from private vehicles to public transportation may play an important role not only in reducing GHG emissions and air pollutants but also in improving the congestion situation in the largest Indian cities. It is important to prioritize the promotion of buses and slow down the penetration of two-wheelers which constituted 74% of the road fleet in 2017 [16]. Large benefits of $PM_{2.5}$ and CO_2 reductions in the PNNL model are achieved because buses dominate passenger service.
- Alternative fuels are important for reducing CO_2 emissions and the dependency on imported energy resources. Over the past decade, oil use in transport has increased by 91% [5], so the production of local biofuels is essential not only for emission reductions but also for enhancing energy security.

Finally, the results of the comprehensive scenario show that it is possible to achieve significant CO_2 and $PM_{2.5}$ emissions reductions by combining various policies. We should note that $PM_{2.5}$ emission reductions would depend on enforcement of stringent emission standards, as we discussed in Section 3.1.

4. Discussion and conclusions

Road vehicles is one of the fastest-growing sources of CO_2 and $PM_{2.5}$ emissions in India [17]. Pollution from the transport sector has become one of the leading causes of increased mortality and morbidity rates in large cities. Given that transportation demand for moving people and goods is going to increase rapidly in the coming years, there is a need to address the issues of emissions and pollution.

The modeling results show that the policies aimed at reducing PM emissions to improve air quality, such as deployment of electric vehicles or increased energy efficiency, have strong linkages with reducing CO_2 emissions. Almost every transportation policy brings strong co-benefits in reducing both CO_2 and $PM_{2.5}$ emissions. Coordination of different policies could bring additional synergy effects in reducing emissions and air pollutants. Robust data collection and data management of the transportation sector are important for the improvement of energy modeling to reduce uncertainties in emissions estimates.

The results of the reference scenario show that India will not be able to reach its decarbonization goals with existing policies. Much more needs to be done to reach net-zero emissions from the national economy as a whole and from the transportation sector. The modeling results demonstrate some wide policy implications of transportation trends in India.

Income-induced growth of cars in India

A common result across the models is an increasing energy intensity of passenger service. Essentially, even after technology-level energy efficiency improvements, the increasing penetration of cars leads to increasing energy intensity of passenger service. This is an important issue, as this reveals the implication of aspirations of people in a rapidly growing economy. As incomes rise, people move from bicycles and shared transport to privately owned two-wheelers and then to privately owned cars. Incentivizing public transportation, creating a seamless infrastructure for the same, and motivating people to use it hence becomes very important. But the experience thus far has been on the contrary, given the very low penetration of cars in India.

Could there be a win-win strategy?

The modeling results reveal an interesting aspect. As far as local air pollution mitigation goes, there is no strategy as successful as electrification of passenger and freight transport. This is because all the other strategies still end up with significant consumption of oil in the transport sector leading to local air pollution. For example, efficiency improvements of internal-combustion engines have physical limits. For CO_2 emissions, however, electrification is successful only if the grid is also decarbonized. It does appear that the most important win-win strategy is the electrification of transport with the decarbonization of the grid, as it would lead to a significant reduction in both local pollution and carbon emissions. Any other strategy will only be partially successful in addressing both these challenges.

Co-benefits versus market economics

This analysis focuses on the co-benefit story, which is a very important part of the decarbonization debate. However, at the same time, it should be highlighted that the co-benefit narrative has been in existence for over two decades now. This argument, while important, in itself has not led to the fast penetration of electric vehicles in India. What has delivered on the ground is the rapid decline in electric vehicles prices. This is also the strength of our analysis as the models capture this key dynamic of market economics that leads to a higher share of cars but a lower share of electric vehicles if these don't become competitive. Hence, while the society can choose a narrative like co-benefit, what might deliver on the ground is falling costs of a particular mitigation option that might make it attractive for investors and buyers. The two have to go together.

Implications for the vehicle manufacturing value chain

The electric vehicles ecosystem is very different as compared to the oil-based vehicle ecosystems. Any country that wants to move towards an electric vehicles future has to move away from the legacy systems, including auto ancillary units and the capabilities that have been built in the last many decades. For any other decarbonization strategy, this trade-off is not there. The automobile companies will have to bite this bullet if they want to reap an early mover advantage. We can expect the legacy investments in the existing auto manufacturing value chain to become a key impediment in a transition towards an electric vehicles future.

The need for a comprehensive approach

This study evaluates alternative strategies for decarbonization of the Indian transport sector, but at the same time also evaluates a comprehensive strategy. Policy makers will need to use elements from different strategies in a complementary way to reap the potential benefits of all of these. Hence, continuous energy efficiency improvements are important, public transportation is important, reducing service demand is important, and so is the electrification of the transport sector along with decarbonization of the grid. Our analysis clearly shows that such a comprehensive strategy, with one of the strategies being the fulcrum, will be the most effective choice for mitigating local air pollution and carbon emissions simultaneously.

Data Availability

The dataset with the modeling results presented in the paper can be found on Zenodo at https://zenodo.org/record/5813751#.YdH1BGjMJPY.

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