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Communication

Re-fueling road transport for better air quality in India

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HIGHLIGHTS

- Analysis of on-road transport emissions from 2010 to 2030.
- Shares of transport emissions by passenger and freight vehicle type.
- Scenario analysis of an early introduction of Bharat-5 vehicle and fuel standards.

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ABSTRACT

Road transport in India plays a vital role in our growing economy. Given an aggressive vehicle sales outlook through 2030, in order to maintain a balance between the energy demand, growing on-road emissions, and overall air quality in the cities, there is a need to implement and enforce Bharat-5 standards (equivalent of Euro-V) nationwide by 2015. Any delay in its implementation or even staggered implementation of the standards will result in a delayed response for improving air quality in the Indian cities.

1. Introduction

According to the 2011 census of India, of the 1.2 billion inhabitants, 30% are designated as urban and this is likely to increase to at least 50% by 2030 (MoUD, 2011). India is a relatively "young" country with at least 600 million inhabitants under 25 years old (Census-India, 2012). India now has the 3rd largest economy in the world—US$4.7 trillion (PPP 2012 est.). With increasing incomes and trade and business opportunities, the demand for motorized transportation to move goods, services, and people is growing. According to the Society of Indian Automobile Manufacturers (SIAM), the sales of domestically manufactured vehicles have increased by at least 15% per annum since 2008 (SIAM, 2013).

A large part of the energy use in the road transport sector is fueled by oil, the combustion of which releases toxic air pollutants and greenhouse gases (GHGs). Current trends in India indicate that on-road vehicle movement is one of the major contributors to the urban air quality problems. The Central Pollution Control Board (New Delhi, India) assessed the contribution of various sectors to ambient particulate matter (PM) pollution in six cities—Delhi, Kanpur, Bangalore, Pune, Chennai, and Mumbai, and concluded that 30–50% originates from the transportation sector (from vehicle exhaust and the resuspension of dust on roads due to vehicular movement) (CPCB, 2010). A pollution exposure assessment in Delhi, suggested that the on-road commuters are exposed to at least 1.5 times the average ambient concentrations in the city (Apte et al., 2011). Other sources of air pollution include fossil fuel burning in the manufacturing industries and power plants, fossil and biomass fuel burning for cooking and heating in the residential sector, garbage burning, and fugitive dust from road and domestic construction activities (Pant and Harrison, 2012). The global burden of disease study for 2010 listed outdoor air pollution among the top 10 health risks in India and estimated 695,000 premature deaths due to outdoor $PM_{2.5}$ and ozone pollution (IHME, 2013). The World Health Organization listed 27 Indian cities in the top 100 cities with the worst air pollution in the world (WHO, 2011).

With the growing number of vehicles and their growing contribution to the air quality problems in the cities, the regulatory agencies need to take a quantum leap, especially in terms of managing passenger traffic and freight on the roads and implement and upgrade nation-wide fuel standards within a short time-frame,

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for long-term gains. In this paper, we present and discuss the energy and emissions outlook for the road transport in India, which could effectively result in a cleaner fleet, cleaner air, and cleaner environment in cities.

2. Data

2.1. Road transport in India

According to the Ministry of Road Transport and Highways, the total registered vehicle fleet in India was 112 million in 2010. This includes all 2-wheeler class motorcycles, all 4-wheeler class passenger cars (including taxis), 3-wheeler class passenger vehicles, light-duty and heavy-duty freight vehicles, passenger buses, and other non-road vehicles like tractors. Of the total registered vehicles, the actual number of vehicles on the road is less than 70% (Auto-Fuel-Policy, 2002; Mohan et al., 2009). This is because private vehicle owners pay a life time registration tax and do not have to register their vehicles annually or when re-sold and the official registration figure would tend to be a cumulative number for a few decades.

While the total number of vehicles increased by 700% between 1990 and 2010, the per capita rate of ownership of private cars in India is still lower than many of the high income and some of the middle income countries. The per capita registered motor vehicle ownership in India is 18 per 1000 people, compared to 797 in the United States, 607 in Canada, 591 in Japan, 519 in the United Kingdom, 271 in Russia, 165 in Thailand, 85 in China, and 50 in Iraq (World-Bank, 2011; Wikipedia, 2013). According to SIAM, the short-term projected growth rate is upwards of 15% through 2015 (SIAM, 2013–2008 to 2013 sales information presented in Supplementary material). We estimate that the total fleet (including passenger and commercial vehicles) will increase four to five folds by 2030, under the business as usual scenario based on the sales estimate for 2012–2013. The projected shares of different vehicle types are presented in Fig. 1.

2.2. On-road emissions

The large mix of on-road vehicle types, with a diverse age mix, and variant operating conditions present a challenging task for estimating the total emissions at the national, state, and city level. The details of the methodology are discussed in detail in Guttikunda and Jawahar (2012) and the total vehicle exhaust emissions are calculated for particulate matter (PM) in two bins (PM_{10}, $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), black carbon (BC), and CO_2. A summary of the methodology is presented in Supplementary material. For each state and city, a one page summary including the share of vehicle type registered, total emissions (for all pollutants) by vehicle and fuel type, and percentage shares of emissions by vehicle and fuel type is presented in Supplementary material. The national totals for the base year 2011 are 253,000 t for $PM_{2.5}$, 51,000 for SO_2, 5 million tons for NO_x, 5.5 million for CO, 1.85 million for VOCs, and 310 million tons for CO_2. The diesel fueled passenger and freight vehicles remain the biggest contributors to the total emissions.

The major cities Agra, Ahmedabad, Bengaluru, Bhopal, Bhubaneswar, Chandigarh, Chennai, Coimbatore, Delhi (including its satellite cities), Dhanbad, Guwahati, Hyderabad, Indore, Jaipur, Kanpur, Kochi, Kolkata, Lucknow, Ludhiana, Mumbai, Nagpur, Patna, Pune, Ranchi, Surat, Trivandrum, Vadodara, Varanasi, and Vishakhapatnam account for 30–40% of the national on-road total emissions. These are all the cities with the vehicle registration information available for 2011, separately from the total vehicle registration numbers for the corresponding state. The total emissions for these cities were calculated as a subset of the state totals, which further allowed for scenarios pertinent to the urban transport policy. The detailed report for each city is presented in Supplementary material.

3. Results and discussions

3.1. Modal shares to total on-road emissions

The contributions of passenger and freight transport sectors are presented in Fig. 2.

Motorized two-wheelers like scooters, small capacity motorcycles and mopeds constitute 70% of the personal vehicle fleet and are more common due to their low initial cost. Relative to the income levels for most households in Indian cities, the fuel costs are high (national average of INR 70 per liter for petrol in 2013) and a fuel efficient engine and convenience of negotiating traffic are major advantages of using this mode.

In bigger cities like Delhi, Mumbai, Hyderabad, Kolkata, Chennai, Ahmedabad, and Bangalore, there is a formal public transportation system and it also benefitted from national programs like Jawaharlal Nehru National Urban Renewal Mission, to better and increase the bus fleet (MoUD, 2012). Since 2009, more than 14,000 new buses were sanctioned to various cities. Besides the intra-city movement, the inter-city transit, especially between the big and medium cities, is a major service provided by the state-run and private-run bus transport corporations (CAI-Asia, 2009). For the Tier II (with population less than 5 million) and Tier III cities (with population less than 2 million), the definition of the public transport is changing. Most of these cities do not have any organized bus services; rather, they are supported by informal para-transit systems, mostly plying on the dominant corridors of the city. Among the para-transit systems, most common are the traditional three-wheeler auto-rickshaws, which can seat up to 4 people and a larger version of the auto-rickshaws, which can seat up to 10 people (also used for short distance inter-city transit). With their ability to negotiate the smaller streets and weave through the mixed traffic, these vehicles form an integral part of movement—for passengers as well as freight and in most cities is also a popular mode of mass transport for school children.

Trucks are the dominant mode of transport of freight between cities, especially from the ports, which may be less than optimal compared to the railways. The large heavy duty container trucks (more than 20 t) are now available in India, servicing from the ports to the cities, which were largely serviced by the 12–16 t trucks in the past. Many cities have a moratorium on heavy duty vehicles from entering the city limits between 6 A.M. and 9 P.M. This was introduced to reduce congestion on the roads and to reduce exposure to harmful diesel fumes during the daytime. This also led to higher proportion of the light-duty trucks and three-wheelers catering to freight movement during the daytime.

The towns and cities towards the Himalayas, in the northern states, are entirely serviced by trucks for freight movement—for every product including fuel. The trucks running these routes in the spring, summer, and fall months are often driven in the lowest gear under full load conditions, which tend to exacerbate the local ambient pollution levels (Nagpure et al., 2011). Overall, the diesel based heavy and light duty vehicles contribute the most to the total emissions.

An often overlooked mode of transportation, especially in rural areas, is that provided by tractors. These heavy duty vehicles are able to cover regions with mud roads, with a wagon hitched at the back and have enough horse power to haul significant loads. They are used to also haul non-agricultural products such as bricks from

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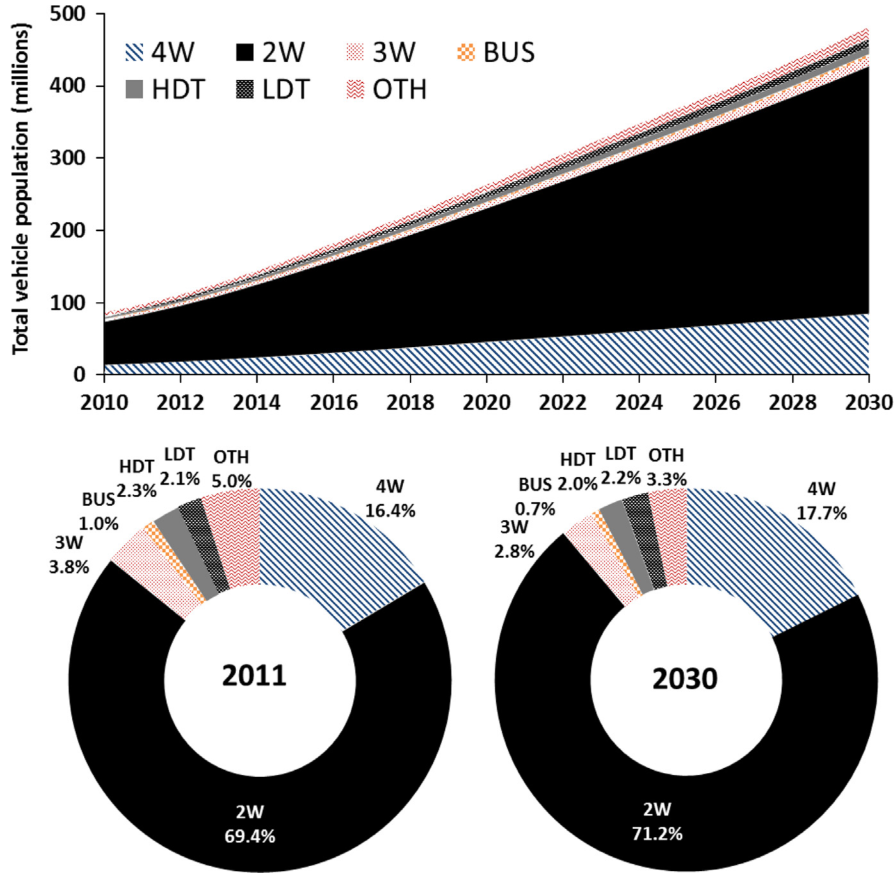

Fig. 1. Projected passenger and commercial vehicle population in India and their shares among the total registered vehicles in 2011 and 2030 (2W=2-wheelers including scooters, motorcycles, and mopeds; 3W=wheelers; 4W=4-wheelers including cars and jeeps; HDT=heavy duty trucks; LDT=light duty trucks; OTH=others including tractors and other non-road vehicles).

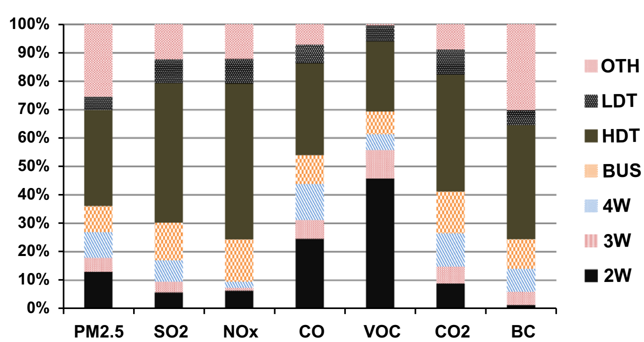

Fig. 2. Percentage share of emissions from passenger and freight vehicles in India for the base year 2011 (2W=2-wheelers including scooters, motorcycles, and mopeds; 3W=wheelers; 4W=4-wheelers including cars and jeeps; HDT=heavy duty trucks; LDT=light duty trucks; OTH=others including tractors and other non-road vehicles).

brick kilns (located most often on fields), mud, gravel and sand for construction, and agricultural waste.

Non-motorized transport (NMT) is a significant mode of transport in India for passenger and freight transport—these may include hand carts, cycles, and horse/camel/cow carts. In urban and rural areas, freight in the form of vegetables, electronics, and construction material, is transported by NMT. These trip lengths are on average shorter than those using motorized transport. Although they do not release emissions themselves, they do share road space with other transport categories and we should not neglect their contribution to the movement of goods and people and overall sustainable development of urban transport systems.

Table 1
Percentage share of emissions from the older vehicles (more than 10 years) for the base year 2011 (HDT=heavy duty trucks; LDT=light duty trucks).

Vehicle	% Fleet	Percentage of total emissions					
		$PM_{2.5}$ (%)	SO_2 (%)	NO_x (%)	CO (%)	VOC (%)	CO_2 (%)
2-Wheelers	17	30	21	32	51	46	21
3-Wheelers	18	42	22	41	54	47	22
4-Wheelers	17	58	21	33	45	50	21
Buses	12	26	14	18	21	30	14
HDTs	16	39	20	30	39	33	20
LDTs	13	46	16	25	33	30	16

The share of emissions from the older vehicles, especially among the light- and heavy-duty vehicles, is significant. This is primarily due to large wear and tear of the engines from overloading, idling, and operating the vehicles at less than ideal conditions, and lack of timely engine maintenance. We estimate at least 30–50% of the total on-road emissions originate from vehicles older than 10 years, which varies from 12 to 17% of the fleet (Table 1).

3.2. Energy and emissions outlook

The projected energy and emissions outlook through 2030 under various scenarios is presented in Fig. 3. The total emissions are a result of multiple factors—including but not limited to, vehicle fuel standards, maintenance of roads and public transport vehicles, transportation and urban planning, and freight movement management.

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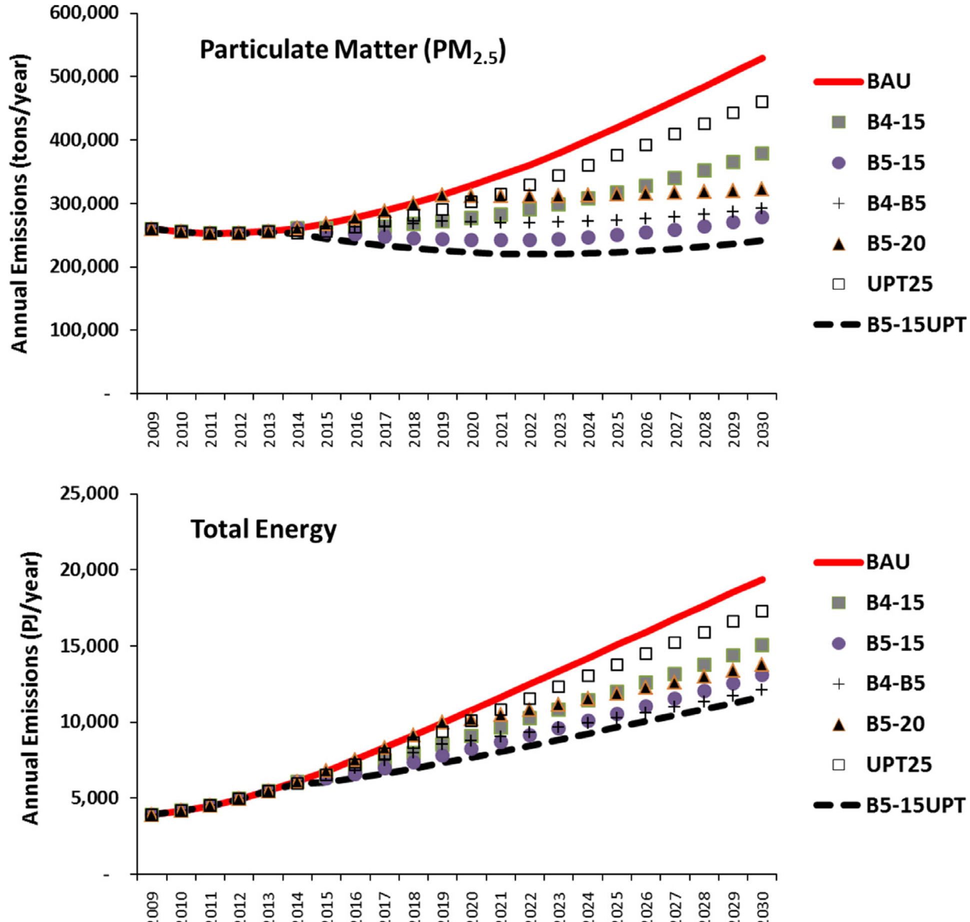

Fig. 3. National outlook on total emissions of $PM_{2.5}$ (tons/year) and total energy (PJ/year) for business as usual and select future scenarios through 2030.

The scenarios presented in Fig. 3 are as follows:

(a) BAU: is business as usual, following no improvements assumed in the current fuel standards
(b) B4-15: is introduction of Bharat-4 standards implemented nationwide by 2015
(c) B4-15-B5-20: is introduction of Bharat 4 standards nationwide by 2015, followed by introduction of Bharat 5 standards nationwide by 2020
(d) B5-20: is introduction of Bharat 5 standards nationwide in 2020, assuming no change in the standards till 2020
(e) B5-15: is introduction of Bharat 5 standards nationwide in 2015
(f) UPT-25: is no change in emission standards and introduction of interventions to change passenger travel behavior resulting in at least 25% reduction in personal passenger travel kilometers
(g) B5-15-UPT-25: is introduction of Bharat-5 standards nationwide in 2015 and introduction of interventions to change passenger travel behavior resulting in at least 25% reduction in personal passenger travel kilometers

For convenience, only the $PM_{2.5}$ and total energy trends are presented in Fig. 3. The total emissions for SO_2, NO_x, CO, and VOC emissions follow the $PM_{2.5}$ trend lines and the CO_2 emissions follow the total energy trend lines. The small improvement in the emissions between 2009 and 2012 is due to the introduction of Bharat-4 fuel standards for 20 cities.

4. Policy implications

For the key pollutants like PM, NO_x, CO, and SO_2, a real impact on air pollution from the transport sector can be achieved only by addressing the issue on multiple fronts. Given the sales outlook (Fig. 1), for an immediate impact on the overall emissions and to maintain the current level of emissions (and to further reduce), the Bharat-5 standards need to be implemented and enforced nationwide by 2015. Any delay in its implementation or even staggered implementation will result in a delayed response (Fig. 3).

4.1. Fuel and emission standards

The chronology of the introduction of the Bharat Stage standards in India is presented in Table 2. While the staggered introduction of the fuel standards is beneficial for the cities in the short run, the overall benefits are lost in transition. For example, the heavy duty vehicles are the largest contributor to the total $PM_{2.5}$, SO_2, NO_x, and CO emissions. While they operate outside the city limits for most of the year, they are likely to utilize fuel of the lower standard and result in higher emissions, irrespective of whether they are operating in the city limits or outside the city limits. In any case, even those vehicles fitted with Bharat Stage IV systems, can have their catalytic converters poisoned when they use lower quality fuel outside the metro cities, resulting in higher emissions.

It is therefore very necessary that the whole country be supplied with the same quality fuel and the latest emission standards be mandated for all vehicles countrywide. Unless this is done, the manufacturers have no incentive to upgrade vehicle emission standards. In various meetings, the officials have suggested that refinery upgradation can cost over INR 50,000 crores and this is why fuel quality cannot be improved in a hurry (1 crores = 10 million). Considering the adverse effects of air pollution on human health, this is not a very large sum to invest. For the emissions presented in Fig. 2 and Table 1, a premature mortality of at least 50,000 per year and tens of millions of asthma attacks per year, was estimated due to exposure to air pollution from on-road emissions, which even in conservative economic terms translate to annual health costs of at least INR 20,000 crores per year (Guttikunda and Jawahar, 2012). For the sake of comparison, it is worth mentioning that a similar amount (more than INR 40,000 crores) has been invested in constructing the metro rail system in Delhi, which only benefits a fraction of the population of one city. There are over 100 million vehicles registered in India, and it should not be too difficult to recover the amount needed, as a special pollution tax within a five year period.

4.2. At the crossroads

Policy measures implemented in isolation, without a multi-pronged approach, will not be very effective in reducing the pollution levels significantly. Providing high quality fuel, setting stringent fuel efficiency standards, and enforcing them is most important. In addition, improvements are necessary for traffic management, vehicle pollution checking procedures, and promotion of behavioral change to use more public and non-motorized transport (Fig. 4). The scenarios presented in Fig. 3 focus on the early introduction of the fuel and emission standards to maintain the status quo, which is still higher than the ambient air quality standards for most cities. Anything in addition to the fuel and emissions standards will result in further reducing the contribution of the transportation sector to ambient air quality problems and result in overall better air quality.

Table 2
Chronology of Bharat Stage standards.

Standard	Date	Region
India 2000	2000	Nationwide
Bharat Stage II (Ref: Euro 2)	2001	NCR*, Mumbai, Kolkata, and Chennai
	2003.04	NCR+13 cities**
	2005.04	Nationwide
Bharat Stage III (Ref: Euro 3)	2005.04	NCR+13 cities
	2010.04	Nationwide
Bharat Stage IV (Ref: Euro 4)	2010.04	NCR+13 cities
	2012.03	NCR+13 cities+7 cities***
	2015	50+ cities

*NCR is the national capital region of Delhi, including Delhi and its satellite cities.
**13 cities are Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, Jamshedpur and Agra.
***7 cities are Puducherry, Mathura, Vapi, Jamnagar, Ankaleshwar, Hissar and Bharatpur.

In the face of rapidly growing economy and resulting increase in the vehicle ownership of individuals, measures introduced to reduce air pollution exposure to vehicle exhaust are losing their effectiveness over time. For example, in Delhi, between 1998 and 2002, the conversion of the entire 3-wheeler and bus fleet from petrol and diesel to CNG, resulted in some improvement in the ambient air quality, but the benefits were soon lost, with the number of the vehicles increasing (especially diesel vehicles) and emissions from other sectors also doubling in the last decade (Guttikunda, 2012). In order to achieve the reduction on a sustained basis, measures to increase share of non-motorized modes as well as public transportation need to be implemented. This will require a concerted and coordinated effort between individuals, urban development authority, and transport departments.

The measure to promote public transport by introducing more buses or to promote NMT by providing more room for walking and cycling is not a simple solution. The measure should not be interpreted as tripling or quadrupling of the bus fleet, but should be interpreted as it could provide the society with the infrastructure for safe and clean mode of transport for a larger mass of passengers, and thus a possibility of more motorized passengers to shift to bus and NMT modes. In India, bus rapid transport (BRT) system pilots were introduced in Pune, Delhi, Ahmedabad, and Indore with mixed results. Besides the infrastructure changes involved in the BRT planning and implementation, the overall structure of the bus operations need to change, with more clean and safe buses on the roads, integrated with intelligent transport systems, walking and biking pathways, and multi-modal central ticketing systems, and more connectivity to different parts of the city, for the BRT systems in India to truly provide the results noticed in Bogota and Curitiba (Hidalgo and Graftieaux, 2008).

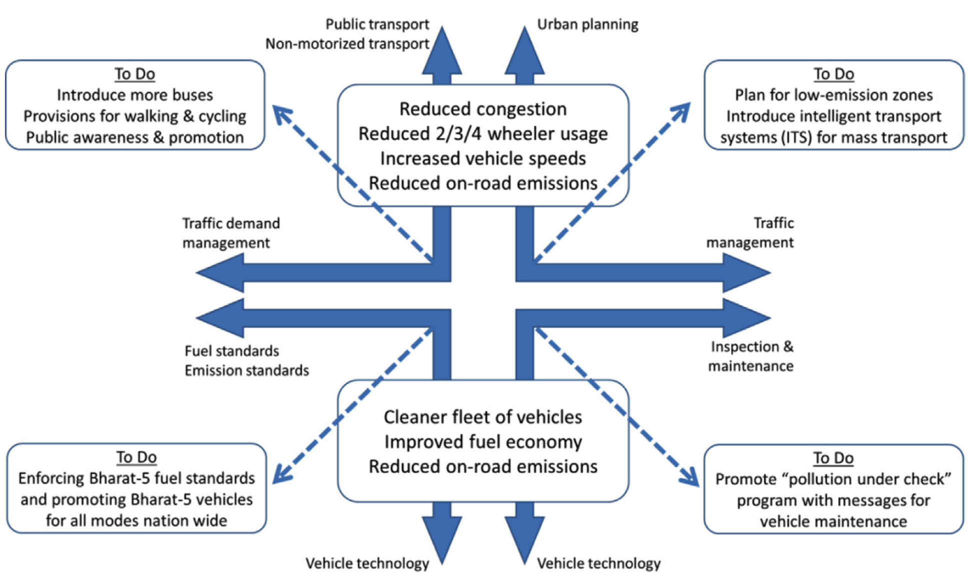

Fig. 4. Technology, policy, and institutional policies that need to be address for better energy and emissions outlook from road transport in India through 2030.

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In conclusion, we cannot use the definition of "big bus carrying 40–80 people per trip" as public transport system. As long as the safe, affordable, and clean transport is provided in volume, via big buses, mini-buses, and three-wheelers, we will be able to reduce the vehicle activity on the road, consequently vehicle exhaust emissions with definite benefits for the public and the environment.

Key messages from this study are

- The fuel and vehicle standards must be improved to Bharat V by 2015, nationwide, in order to maintain the status quo on the total vehicle exhaust emissions
- Goals must be set to clean up the older vehicles, especially those from the freight sector
- Safe and convenient walking and cycling facilities on all arterial roads must be advocated for all urban areas
- Affordable, safe, and convenient public transportation systems must be promoted in all cities

Targets should be set to improve and enforce inspection and maintenance programs, for long term gains in fuel economy and overall emissions.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2013.12.067.

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