Simple Interactive Models for Better Air Quality

Road Transport in India 2010-30

Emissions, Pollution & Health Impacts

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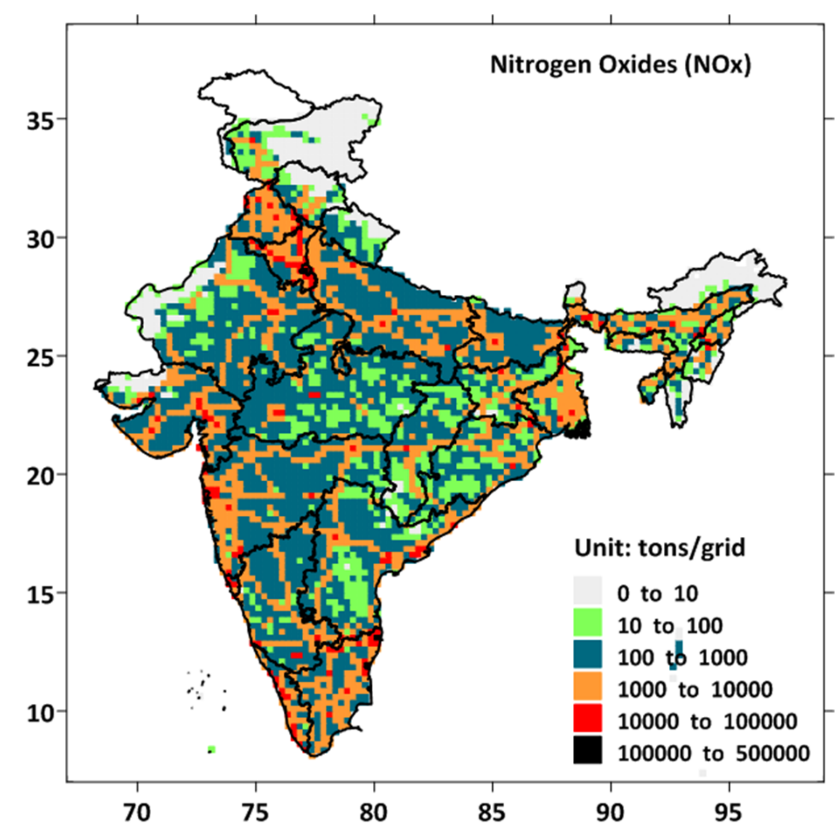
November, 2012



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Road Transport in India 2010-30: Emissions, Pollution & Health Impacts

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Chapter Zero

India is the 7th largest country in the world covering an area of 3.5 million km^2 and has a population of 1.2 billion. According to 2011 census figures, 30 percent of India's population lives in urban areas and the rate of urbanization is growing steadily due to the push/pull effects of employment opportunities and the declining viability of the agricultural sector. This, in addition to the fact that India now has the 4th largest economy in the world - $4.463 trillion (2011 est.), has resulted in a large and growing movement of goods, services, and people fuelled by trade and employment opportunities – almost all of which is powered by fossil fuels.

India is a relatively "young" country. Of the population of 1.2 billion, 600 million are under 25 years old. With growing incomes and the need to travel on a regular basis, the demand for personal transportation is growing in India. The sales of domestically manufactured vehicles saw at least 15-percent increase per annum since 2008[1]. A large part of the energy use in the transport sector (road and rail) is fueled by oil, the combustion of which releases toxic air pollutants and greenhouse gases (GHGs).

Figure 1: Caption from "Mail Today" on March 3rd, 2009


Capital has more toxic particles in its air than other major Indian metros

DELHI IS INDIA'S ASTHMA CAPITAL

DELHI has the highest levels of Respirable Suspended Particulate Matter (RSPM) among the four metros, exposing its residents to a greater risk of asthma than people elsewhere in the country.

Acceptable levels of RSPM should not be more than 60 microgram (mg) per cubic meter (cu m) annually. In 2008, Delhi's

By Meenal Dubey in New Delhi

RSPM was recorded at a shocking 149 mg/cu m, according to a report published by the Central Pollution Control Board (CPCB) with the help of data collected between January and August 2008.

It is no secret that India's capital is highly

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Current trends indicate that on-road vehicle movement is the major contributor to the growing air quality related problems at the urban level and carbon dioxide (CO_2) emissions at the national level. A study conducted by the Central Pollution Control Board (CPCB), New Delhi, India, in six cities – Delhi, Kanpur, Bangalore, Pune, Chennai, and Mumbai, concluded that the transport sector contributes 30-50 percent to the ambient particulate pollution problems – either directly from the vehicle exhaust or indirectly via the resuspension of dust on roads due to vehicular movement[2]. The share of transport emissions contributing to the ambient air quality ranges from 30-50 percent for most of the cities in Asia[3].

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[1] The vehicle sales information at the national level is obtained from Society of Indian Automobile Manufacturers @ http://www.siamindia.com

[2] A detailed report on the methodology, results, and supporting documents are available @ http://cpcb.nic.in/Source_Apportionment_Studies.php

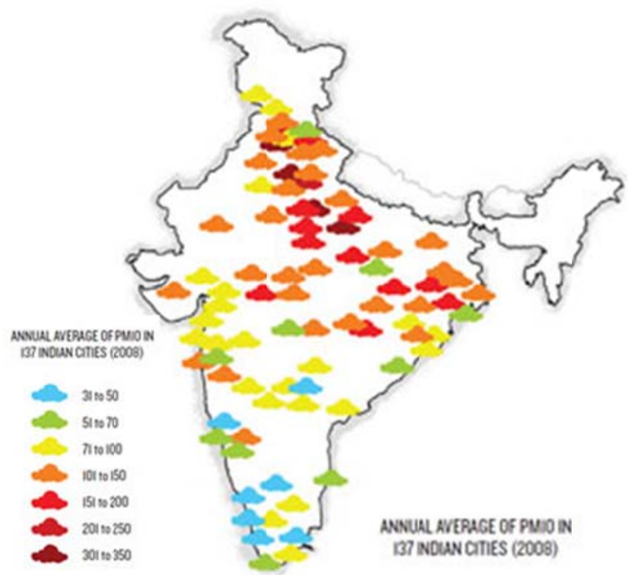
[3] Tools for Air Quality Management, ESMAP Publications, The World Bank (2011) @ http://www.esmap.org/node/1159

Exposure to pollutants such as particulates[4] and ozone are responsible for negative health impacts[5]. An extensive epidemiological literature relates $PM_{2.5}$ to adverse health impacts[6]. In epidemiologic cohort studies of long-term exposure (which form the basis of the exposure-response functions used in health impact assessment) $PM_{2.5}$ is the most robust indicator of adverse (mortality) impacts[7]. WHO estimated a total 154,000 premature deaths due to outdoor air pollution in India.

In 2009, a study correlating the ambient concentrations of PM_{10} and hospital admissions, dubbed Delhi as the asthma capital of India. A study conducted by the University of California (Berkeley) suggested that the on-road exposure to air pollution is at least 1.5 times worse than the average ambient concentrations[8].

In 2011, the World Health Organization (WHO) studied publicly available air quality data from 1100 cities, including cities with population of more than 100,000 people, and put many of the Indian cities in the top 100 cities with the worst air pollution[9].

Figure 2: Ambient PM_{10} concentrations in Indian cities



The range of the PM_{10} concentrations measured in 130 cities in India[10] is presented in **Figure 2**; most of them exceeding the national ambient annual standard of 60 $\mu g/m^3$. The standard for $PM_{2.5}$ is 40 $\mu g/m^3$.

[4] Particulate Matter (PM) is also referred as dust or aerosols and two size fractions are listed as criteria pollutants. (a) PM_{10} = PM with aerodynamic diameter < 10 μm (also known as coarse PM) and (b) $PM_{2.5}$ = PM with aerodynamic diameter < 2.5 μm (also known as fine PM). In India, $PM_{2.5}$ was added to the list of criteria pollutants in November, 2009.

[5] Directory of resources on transport, health, and environment in the developing countries by WHO @ http://www.who.int/heli/risks/urban/transpdirectory/en/index.html

[6] Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects, Special Report 17, published by the Health Effects Institute (USA) @ http://pubs.healtheffects.org

[7] Brauer et al., "Global burden of disease attributable to outdoor air pollution", published in Environmental Science and Technology, 2012 @ http://www.dx.doi.org/10.1021/es2025752

[8] Apte et al., "Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India" published in Atmospheric Environment, 2011 @ http://www.sciencedirect.com/science/article/pii/S1352231011005206

[9] Database of outdoor air pollution in world cities by World Health Organization (WHO) @ http://www.who.int/phe/health_topics/outdoorair/databases/en/index.html

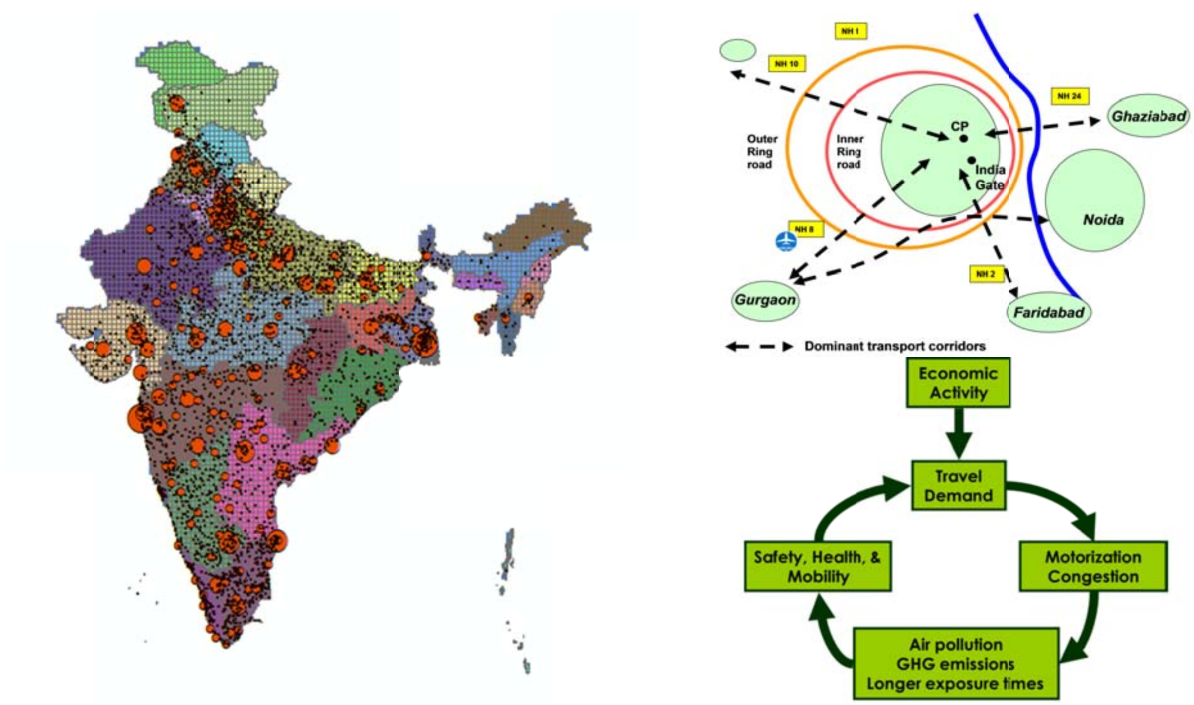
[10] Environmental Data Bank, operated by the CPCB, New Delhi, India @ http://cpcbedb.nic.in/

In India, three major factors are responsible for the increase in emissions from the transport sector

(a) Urban population, an estimated 30 percent is concentrated in less than 5 percent of the land cover and the activity therein accounts for a large share of the national economy
(b) The growing demand for mobility
(c) The demand for goods, which is mostly met by road and rail transport

Growing industrial conglomerations and information technology parks, under the Special Economic Zone (SEZ) schemes have become hubs of economic activity in both tier 1 and tier 2 cities. For example, in Cochin city, the SEZ covers an estimated 103 acres of land and ~100 factories manufacturing ready-made garments, rubber gloves, electronic items, software, hardware, food items and jewelry. Besides the major cities like Delhi, Mumbai, Chennai, Kolkata, Bangalore, Hyderabad, and Ahmedabad, the secondary cities (with population more than 2 million) like Pune, Surat, Indore, Bhopal, Nagpur, Jaipur, Varanasi, Nagpur, Agra, Guwahati, Patna, Kanpur, Panaji, Trivandrum, and Cochin, are demanding personal and public transport, putting pressure on local infrastructure.

Figure 3: Number of cities in India and travel demand from the satellite cities in Delhi



The increasing geographic size of the cities also means greater travel between areas within the city. For example, once distant satellite cities to Delhi, NOIDA and Gurgaon have since become part of the Delhi administration, forming the National Capital Region (**Figure 3, top right**). On a daily basis, the travel into and out of Delhi to these cities account for nearly 30-40 percent of the passenger trips[11]. Similarly, a large number of residential parks sanctioned in the cities of

[11] Surveys conducted by the Central Road Research Institute (CRRI), New Delhi, India @ http://www.crridom.gov.in

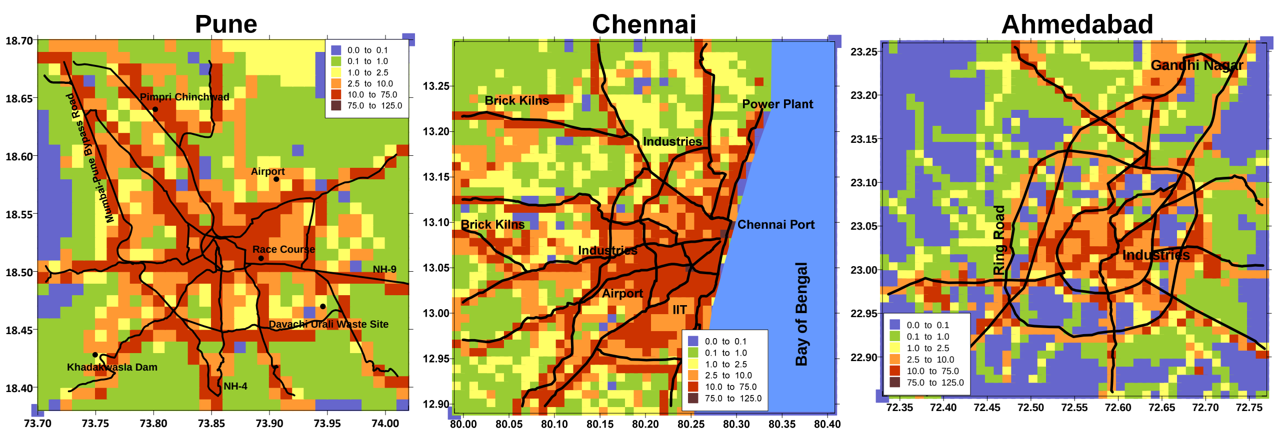
Hyderabad, Bangalore, Pune, Bhopal, and others, are located in what were once outskirts of the cities, resulting in a greater need for transport and infrastructure. The increase in traffic along with inadequate infrastructure facilities is adding to increasing road transport emissions in India.

According to energy scenarios developed by the US Energy Information Administration (EIA), India's transportation energy use will grow at about 5.5 percent a year – much higher than the world average of 1.4 percent per year[12]. Through 2035, transport energy is expected to more than quadruple and with the highest demand coming from the passenger vehicles.

Increasing economic activity will necessitate large and recurring investments in cities. Cities need to integrate strong environmental policies at the planning stages itself, else the increase in pollution will be harder to address over time. Unfortunately, GHG emissions and their mitigation have remained low in terms of priorities of municipal agencies. Instead, a greater demand for action likely to result when the health impacts of the growing air pollution from the transport sector are illustrated (**Figure 2** and **Figure 4**). This is primarily due to two reasons

1. The regulatory bodies are more concerned about the criteria pollutants that they are mandated to regulate
2. While GHGs are responsible for climate change, the impacts of climate change are largely global and efforts to mitigate emissions at the local level do not have an urgency

Figure 4: On-road vehicle exhaust PM_{10} emissions (Units: tons/square km) in 2010



While the message is clear; with the growing air pollution and GHG emissions from the transport sector in cities and at the national level, regulatory agencies will have to take a quantum leap, especially in terms of managing traffic in cities and freight at the state and the national level. They will have to implement radical solutions ranging from technical, social, policy, to economic, within a short time-frame for long-term gains. This study focuses on the energy and emissions outlook for the transport sector in India which could effectively result in a co-benefits framework for better air quality management in the cities and a national climate policy dialogue.

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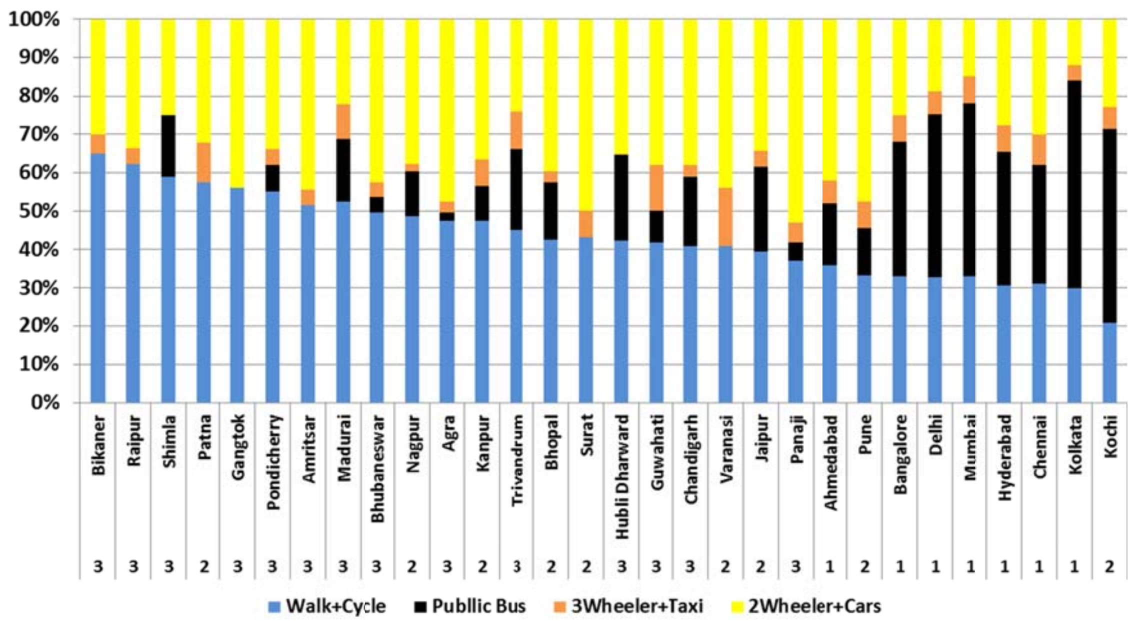
[12] "International Energy Outlook – Transportation Sector Energy Consumption, 2011", US EIA, Washington DC, USA @ http://www.eia.gov/forecasts/ieo/transportation.cfm

On-Road Passenger Travel in India

The demographic (a young workforce), economic and geographical conditions in India are ripe for the growth of the automobile manufacturing sector. The projected growth rate is upwards of 15 percent in the light-vehicle segment and commercial-vehicle segment during 2010-15. A summary of a survey (conducted in 2008) of passenger travel characteristics in Indian cities and their modal shares is presented in **Figure 5** and passenger travel behavior is presented in **Figure 6**[13].

Figure 5: Urban passenger modal shares in Indian cities

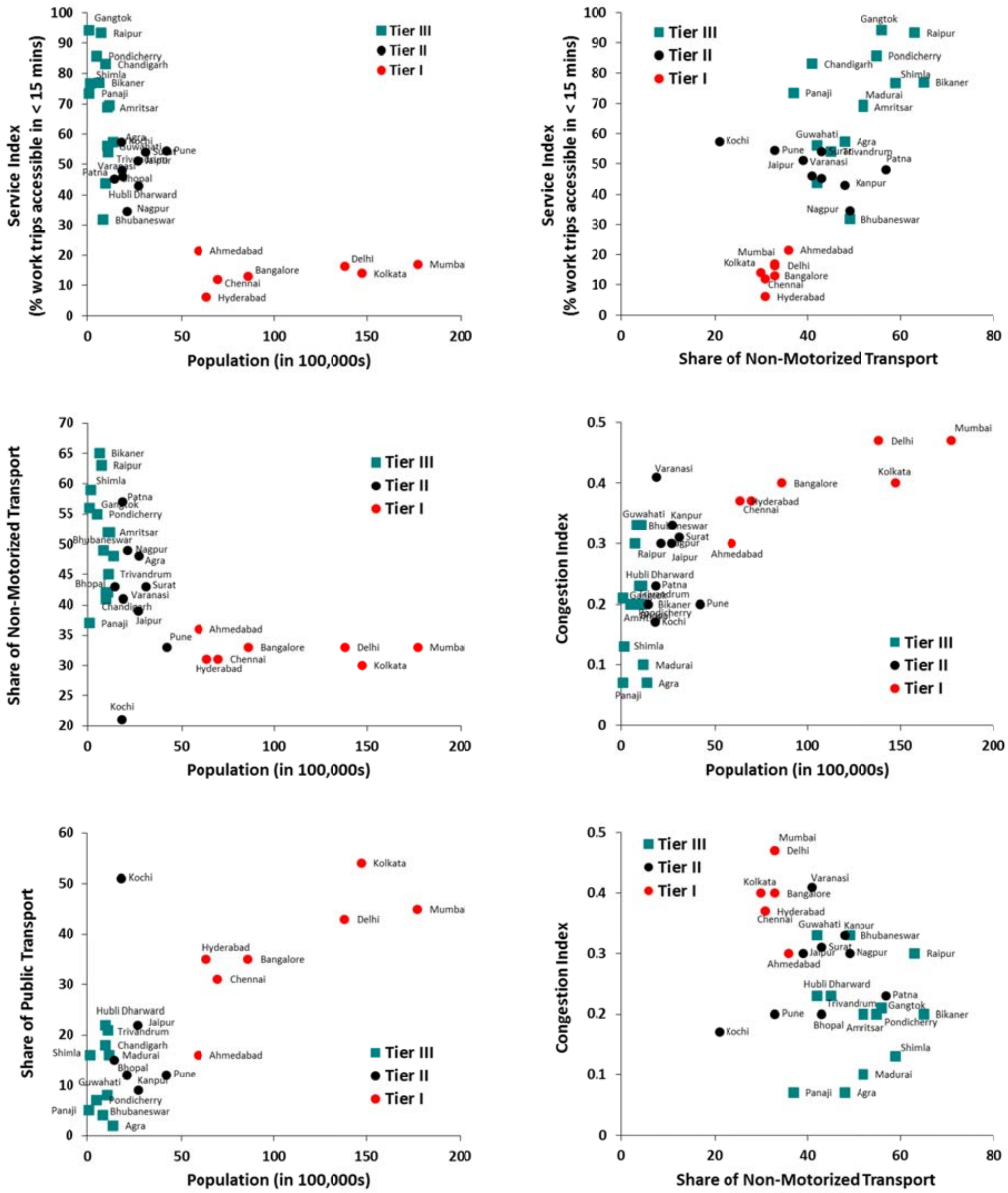


The cities are arranged in the descending order of the non-motorized transport (NMT) share and the number below each of the city's name represents its Tier. The megacities (light dots, referred as the Tier I cities, with population more than 5 million) perform poorly compared to the medium size cities (dark dots, referred as Tier II cities, with population between 2 and 5 million) and then the tertiary cities (squares, referred as Tier III cities, with population less than

[13] "Traffic & Transportation Policies and Strategies in Urban India" The Ministry of Urban Development, The Government of India (2008) @ http://urbanindia.nic.in/moud/theministry/ministryofurbandevelopment/main.htm

2 million). The cities with the lowest service index are Delhi, Mumbai, Chennai, Hyderabad, Kolkata, Ahmedabad, and Bangalore.

Figure 6: A comparison of passenger travel patterns in the Indian cities



The panels present the relationship between the city population and city travel service index (defined as the percentage of work trips accessible in less than 15 minutes of travel time) and its relationship with various travel modes as the share of passenger trips. As the cities are expanding geographically and in numbers, the need for motorized (self or public) transport is becoming imminent and the shares of NMT (walking and cycling) dwindling.

The correlation between commuter service index and the share of NMT is very strong, indicating a negative effect on urban mobility and accessibility. The current trends suggest that, as the cities graduate from Tier III to Tier I, the share of short trips, which are otherwise dominated by NMT mode, tend to decrease and get replaced by motorized transport. The correlation between the congestion index and the share of NMT trips clearly indicates this shift. NMT is the main mode of transport for more than 40 percent of commuter trips. A significant amount no doubt.

Additionally there is very little by way of numbers to capture the use of cycles in rural areas. The Census of India indicates that more people can now afford to own a cycle than ever before. In 2005, more than 40 percent of the Indian households own a bicycle. Unfortunately, those using cycles are not the power elite and their needs like cycle tracks and road safety are ignored. As the income of this strata increases, they most often move on to two-wheelers. This would obviously have an impact on transport emissions. To prevent this and to improve options for everyone in urban areas especially where trip lengths are very small – having a very real and concerted focus on NMT is crucial for cities – and it should be encouraged across all income groups and not just limited to the lower income sections.

The role of para-transit mode aka 3-wheeler auto-rickshaws and taxi services, cannot be ignored in urban India. The para-transit transport shares are small and tend to follow that of public transport; meaning as the cities are graduating from Tier III to Tier I, they do tend to put more emphasis on the public and para transport, by putting more buses on the road and/or by promoting the shared-transit systems like 3-wheelers, taxis, and other alternatives.

The access to the public transport is high in the Tier I cities and is expected to further grow under the JNNURM program[14]. In most of the cities, motorcycles are the dominant mode of transport, with vehicle shares as high as 70 percent in the Tier I and Tier II cities. This is the due to the availability of motorcycles (lower prices compared to cars and easy Bank loans) and lower operating costs (better mileage compared to cars, convenience of parking at most locations, and cheaper than public transport). It appears that public transport cannot attract these road users unless the fare structure is less than the marginal operating cost of using a motorcycle[15]. While, there is an increased awareness of need for more public transport facilities, the supply side has been weak. A lack of necessary infrastructure to manufacture and supply 70,000 buses under the JNNURM program is hindering an aggressive promotion of public transport in the Tier II and Tier III cities.

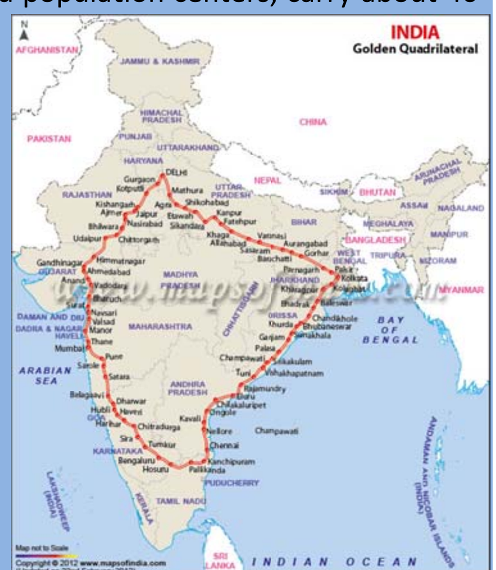
[14] The Jawaharlal Nehru National Urban Renewable Mission (JNNURM) under the Ministry of Urban Development, The Government of India @ http://jnnurm.nic.in

[15] Mythologies, Metro Rail Systems and Future Urban Transport, published in Economic & Political Weekly, 2008 @ http://www.epw.in/special-articles/mythologies-metro-rail-systems-and-future-urban-transport.html

In the public transport sector, the Bus Rapid Transit systems (BRT) are the current flavor of the day as far as urban transport policy is concerned. The idea of a BRT system is that by allowing buses to ply on dedicated “bus-lanes”, travel times of those using buses would reduce, thus providing an incentive for people to use public transport. Like most policies however, it is not a simple matter of only providing a bus lane. For it to be successful, one needs to have adequate busses, proper design of bus stops and routes, and most importantly – enforcement of bus lane use so that other vehicles do not use it and cause congestion. Several BRT systems in addition have a NMT component (walking/cycling lanes) and enforcement and maintenance of these is also necessary. The most common citation for a successful BRT system was that of the city of Bogota in Columbia. In India, Pune, Delhi and Ahmedabad have tried, rather unsuccessfully to implement BRT systems on large scale. The lack of success is due to a combination of factors, including – lack of enforcement, lack of busses, lack of maintenance of the bus fleet, bad design of routes, and a lack of a multipronged effort to improve public transport and NMT infrastructure concurrently.

Box: Road Network in India

India has the 3rd largest road network with 3.3 million km of road, including 650 km of expressways, 67,000 km of national highways, 132,000 km of state and trunk highways, 468,000 km of major district roads, and more than 2.6 million km of rural and other roads. Roadways are integral to transport in the country and are the main method for movement of freight, with 40 percent of the villages in India lacking access to all-weather roads and remain isolated during the monsoon season. The National Highways Authority of India (NHAI) is the principle government body responsible for the upkeep of roads and has in the recent years undertaken a series of large scale infrastructure projects to increase the network of existing highways. According to NHAI, the national highways account for about 1.7 percent of the road network, many of which are linked to major economic and population centers, carry about 40 percent of the total traffic, supports 65 percent of freight movement, and 80 percent of the passenger traffic in the country. This has grown from 15.4 percent for passenger traffic and 13.8 percent of freight traffic in 1950 (Annual report of MoRTH).



The Golden Quadrilateral is thus far the largest highway project in India. It is named such because it is a network of highways that connects the 4 main metropolises of India - Delhi, Mumbai, Chennai and Kolkata, along with other cities such as Bangalore, Pune, Ahmedabad, and Surat. It was completed in January 2012 at a cost of INR 600 billion. Although the highway accounts for just two percent of the country's total road infrastructure, it carries 40 percent of the total national traffic.

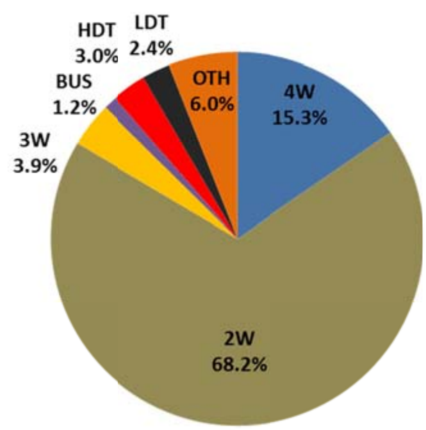
On-Road Vehicle Fleet in India

The total registered vehicle fleet in India is 112 million in 2010[16]. The shares of cars, multi-utility vehicles (MUVs), taxis, 2-wheelers (2Ws), 3-wheelers, buses, heavy duty trucks (HDT), light duty trucks (LDT), and others including tractors, is presented in the following Tables and Figures. In **Figure 7** and **Table 1**, the category 2Ws includes 2-stroke and 4-stroke scooters, mopeds, and motorcycles, 4Ws include cars, MUVs, and taxies, BUS includes public transport, state carriage, and long haul buses, and OTH includes tractors and other vehicles, for all fuel types.

Motorized two-wheelers like scooters, small capacity motorcycles and mopeds are very popular due to their cost, fuel efficiency and ease of use in congested traffic[17]. All the vehicles (motorized and non-motorized) are utilized for multiple purposes, for both passenger and freight transport, varying loading conditions, at all terrains from high altitude Kashmir to the plains of Tamilnadu and Kerala.

The demand for transportation services outstrips the supply of options in most parts of the country. The main reason for this is economic - people have to make do with available transport modes in most cases - be it a growing family, who still use a two-wheeler or travelers who hitch a ride on any available locomotive contraption to go between villages.

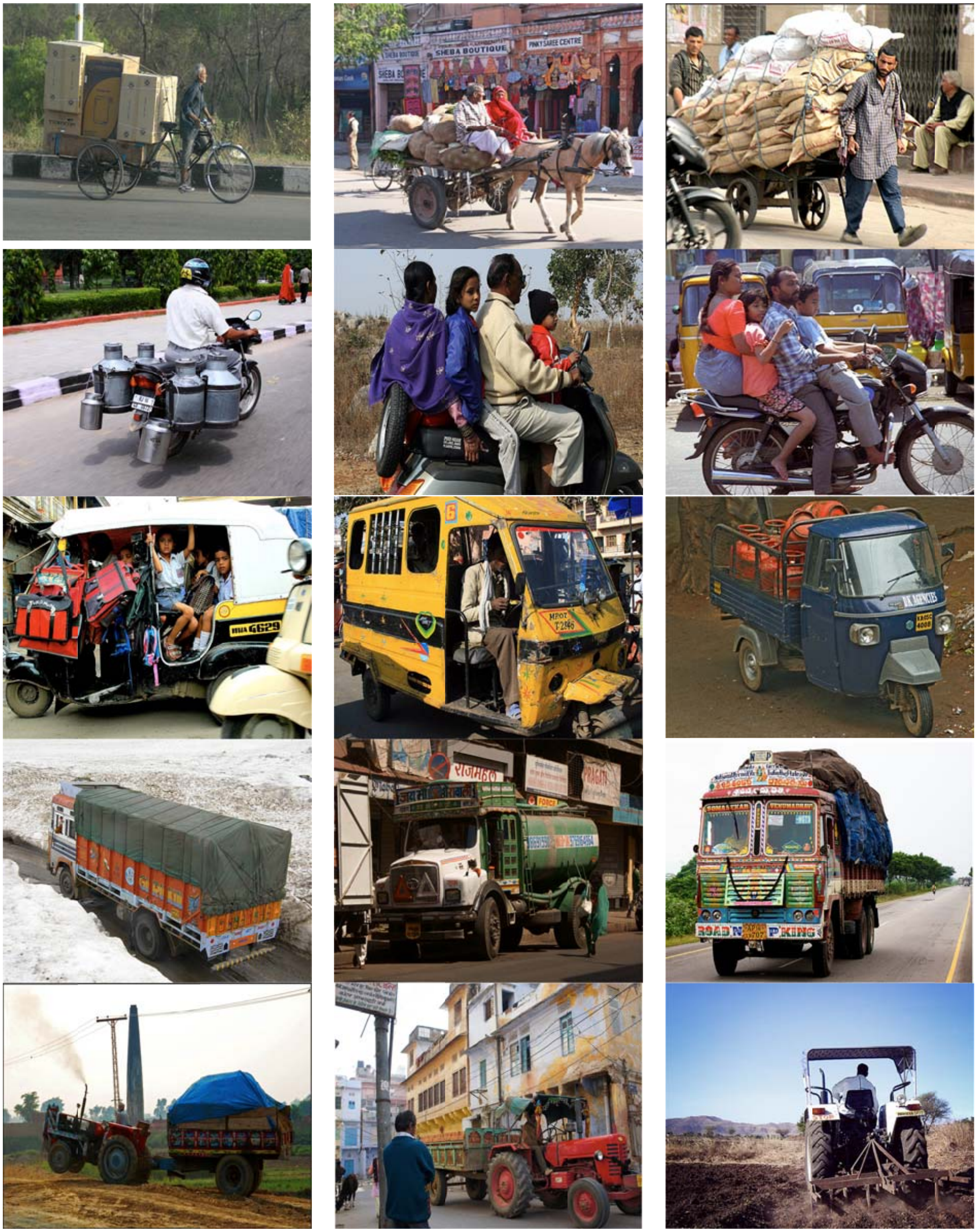
Figure 7: Share of registered vehicles in India in 2010



[16] Annual report (2009) published by the Ministry of Road Transport and Highways (MoRTH), the Government of India, New Delhi, India @ http://morth.nic.in/showfile.asp?lid=839

[17] The vehicle sales information at the national level is obtained from Society of Indian Automobile Manufacturers @ http://www.siamindia.com

Examples of On-road transport in India[18]



[18] All the pictures are obtained from flickr's open-source portal and should not be used for any commercial publication without the photographer's permission

Non-motorized transport is an invisible fleet category in India - 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 would like to acknowledge their contribution to the movement of goods and people.

Two-wheeler scooters and motorcycles are the most economically viable personal transport vehicle. Fuel in India is not inexpensive, and hence the fuel economy and convenience of negotiating traffic are major advantages of using them. While rules regarding the number of people traveling on them are present - especially in cities - they are often ignored. It is not unusual to have 2 or more persons riding a two-wheeler, which is meant for only 2 people.

Negotiating tiny by-lanes and weaving through traffic is the main advantage of the three-wheeler light-duty passenger vehicles. These form an integral part of movement in the cities – for passengers, freight, and when in session catering to the schools in the cities. Three wheelers are also used as the para-transit systems in areas that are served by metros (in cities like Mumbai, Kolkata, Delhi, and Chennai). Smaller towns usually operate six-seater vehicles that provide services similar to mini-buses (by plying a dominant route - into town for example). Emissions from these vehicles are a significant contributor to air pollution. In response to this, the Delhi Government mandated the conversion of the entire fleet of autos to CNG in early 2000, followed by similar initiatives in other cities to supplement the fuel with CNG or LPG.

Trucks are the main mode of transport of freight between cities, across the country, especially from the ports - on roads that may be less than optimal. The large heavy duty container trucks (more than 20 tons) are now available in India, servicing from the ports to the cities, which was largely serviced by the 12-16 ton trucks. Most of the cities in India have a moratorium on the heavy duty vehicles from entering the city limits between 6 AM and 9 PM, which was introduce to reduce the possible 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 for freight movement during the daytime.

The towns and cities in the Himalayas are entirely serviced by trucks - 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 emission and pollution levels in these areas.

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 and with a wagon hitched at the back have enough horse power to haul significant loads. They are used to also haul non-agricultural products such as bricks from brick kilns (located most often on fields), mud, gravel and sand for construction, agricultural waste etc.

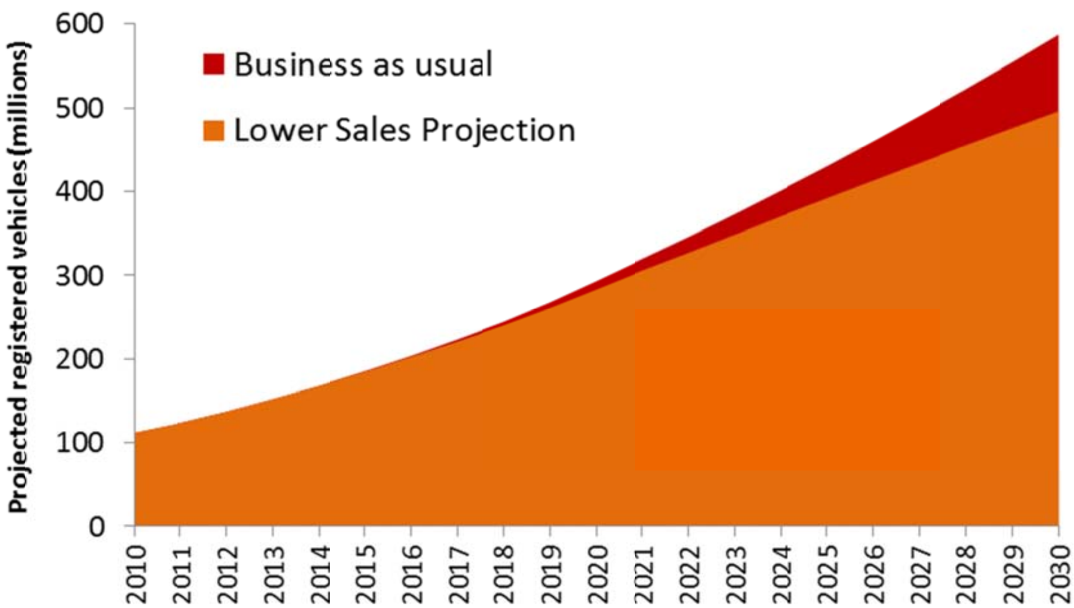
Table 1: Total number of registered vehicles in India for 2010 by State							
	2W	**3W**	**4W**	**BUS**	**LDT**	**HDT**	**Total**
STATES							
Andhra Pradesh	2,571,000	97,500	860,500	29,000	101,500	709,000	**7,851,000**
Arunachal Pradesh	232,500	4,000	140,000	5,500	50,500	69,500	**24,000**
Assam	337,500	26,500	192,000	24,000	26,500	60,500	**1,225,000**
Bihar	1,458,500	68,500	288,500	11,500	66,500	147,500	**2,040,000**
Chattishgarh	4,454,500	328,500	1,156,500	111,500	191,000	532,000	**2,012,000**
Goa	2,426,000	596,500	1,049,500	91,000	342,000	131,500	**653,000**
Gujarat	4,356,500	81,000	456,500	31,000	72,000	752,000	**10,720,000**
Haryana	9,483,500	795,000	2,482,000	95,000	493,000	935,500	**4,369,000**
Himachal Pradesh	98,000	5,500	30,000	4,000	2,500	10,000	**502,000**
Jammu & Kashmir	42,500	6,500	71,500	4,000	6,000	24,500	**667,000**
Jharkhand	30,000	3,000	31,500	1,000	6,000	6,000	**2,041,000**
Karnataka	48,500	17,500	99,500	5,500	23,500	72,000	**6,774,000**
Kerala	1,906,500	66,500	221,000	21,500	86,000	214,000	**4,637,000**
Madhya Pradesh	3,326,500	71,500	571,000	25,000	25,000	636,000	**5,749,000**
Maharashtra	4,379,500	137,500	815,500	67,500	140,000	818,000	**14,284,000**
Manipur	6,000	-	22,000	2,000	1,000	3,000	**150,000**
Meghalaya	9,493,500	286,500	1,439,500	130,500	340,000	661,500	**155,000**
Mizoram	79,500	23,000	21,000	2,500	10,000	15,000	**78,000**
Nagaland	530,000	17,000	128,500	6,000	19,500	62,000	**267,000**
Orissa	7,913,000	140,000	1,086,500	44,500	128,000	1,037,000	**2,516,000**
Punjab	1,873,500	56,500	653,000	34,000	9,500	315,500	**4,655,000**
Rajasthan	2,571,000	97,500	860,500	29,000	101,500	709,000	**6,358,000**
Sikkim	232,500	4,000	140,000	5,500	50,500	69,500	**34,000**
Tamil Nadu	337,500	26,500	192,000	24,000	26,500	60,500	**12,352,000**
Tripura	1,458,500	68,500	288,500	11,500	66,500	147,500	**151,000**
Uttarakhand	4,454,500	328,500	1,156,500	111,500	191,000	532,000	**763,000**
Uttar Pradesh	2,426,000	596,500	1,049,500	91,000	342,000	131,500	**10,349,000**
West Bengal	4,356,500	81,000	456,500	31,000	72,000	752,000	**2,942,000**
UNION TERRITORYS							
Andaman & Nicobar	39,500	4,000	13,500	1,000	500	3,000	**62,000**
Chandigarh	475,500	3,000	230,000	2,500	10,000	2,000	**723,000**
Dadra & Nagar Haveli	33,000	1,000	18,000	500	2,500	8,000	**63,000**
Daman & Diu	40,000	2,000	20,000	500	3,500	3,500	**70,000**
Delhi	3,572,500	239,000	2,065,000	126,500	124,500	90,000	**6,218,000**
Lakshadweep	5,500	500	500	500	1,000	500	**9,000**
Puducherry	403,500	7,000	76,500	5,500	11,000	14,000	**518,000**
TOTAL	**76,600,000**	**4,400,000**	**17,300,000**	**1,200,000**	**3,100,000**	**9,700,000**	**112,000,000**

All the numbers are rounded to nearest 500.

The 22 cities are analyzed separately, as subsets of their respective state totals. The city travel characteristics are generally different from those observed in the remainder of the country.

While the total vehicle numbers have increased significantly between 1990 and 2010, the per capita rate of ownership of private cars in India is still lower than many of the European Nations, United States, and Canada. As incomes rise, car ownership will increase proportionately and consequently the total emissions and pollution. The proportion of 4-wheelers (including taxis) is 30 percent higher in the cities compared to the national averages. We estimate that the total fleet will increase four to five folds by 2030, based on high and low sales growth scenarios. For the high scenario we assumed that the current trend in the sales will persist with no additional programs for curtailing the sales. In the low sales growth scenario, we assumed acceleration of urban transport planning in the cities, which includes an aggressive promotion of public and non-motorized transport. We expect these measures to be policy, institutional, and economical in nature, which will affect growth in the passenger vehicle sales. In 2030, the total vehicle fleet size is expected to be 16 percent lower under accelerated urban transport planning.

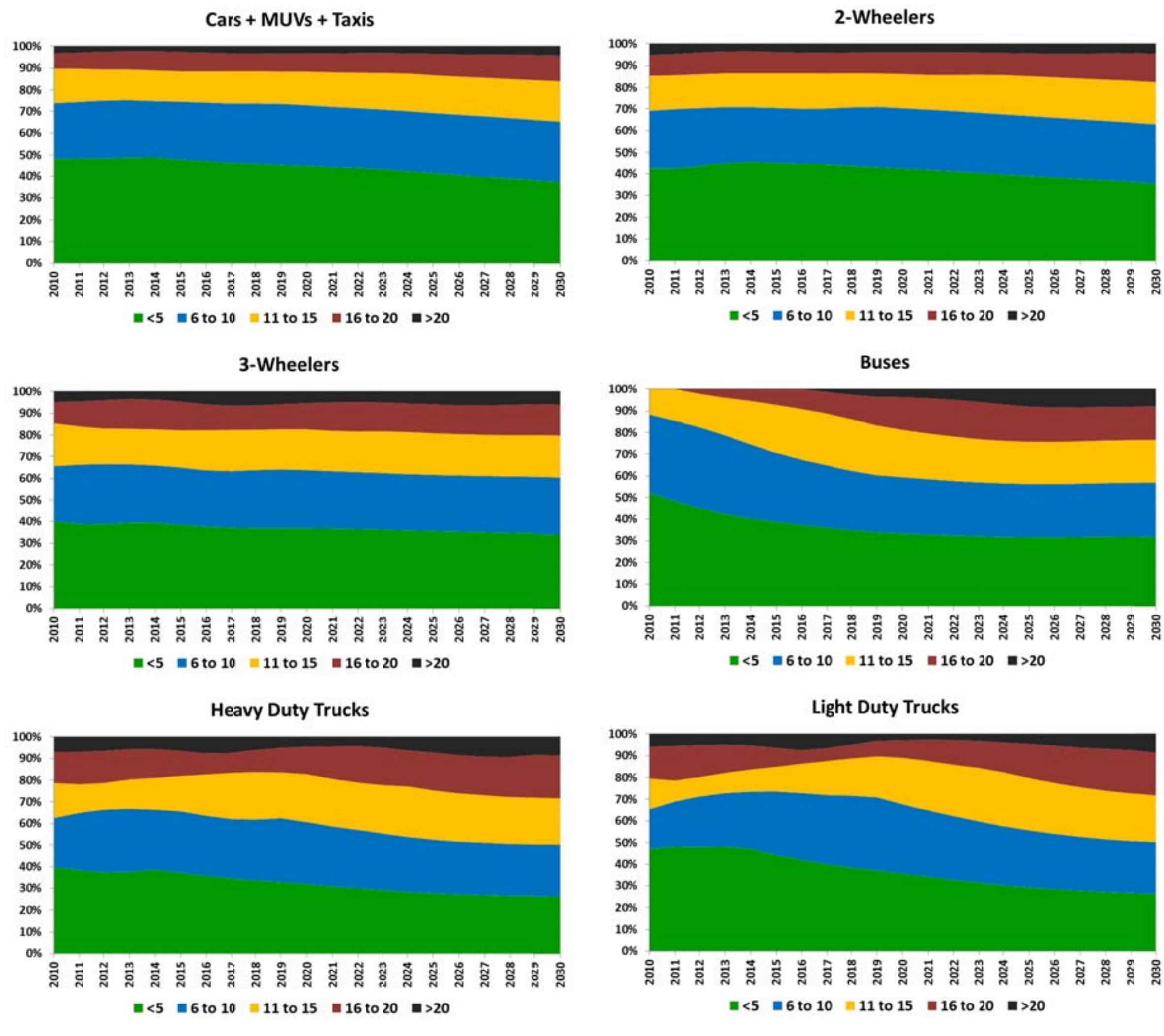
Figure 8: Total vehicle population in 2030 under high and low sales projections



The projections in vehicle sales do not include any technological advances in the engines and expected changes in emission standards in the future years. Both the sales projections are estimated "what-if" scenarios. Under the business as usual scenario, the sales growth is maintained from 10 percent per year tapering to 6 percent by 2030, for passenger vehicles. Under lower sales growth, the rates are tapered to 3 percent starting in 2015. We did not change the anticipated sales for the commercial vehicles (LDT, HDT, Tractors, and Others) between the scenarios.

The age mix of the vehicles is corroborated with the information on national vehicle sales from the Society of Indian Automobile Manufacturers (SIAM, New Delhi, India) and average age of the vehicles on-road, which was deduced from surveys conducted by the Transport Research and Injury Prevention Program (TRIPP) at the Indian Institute of Technology (New Delhi, India). The surveys included data from "pollution under check" program in India and physical surveys at the petrol stations in Delhi. In **Figure 9**, the age mix of the vehicles is presented for the period of 2010 and 2030, based on all vehicle sales (current and projected) in the last 25 years, for each corresponding year. It is not necessary that the vehicles as old as 25 years are running on the road, but this is an indication of possible vehicle mix on the road.

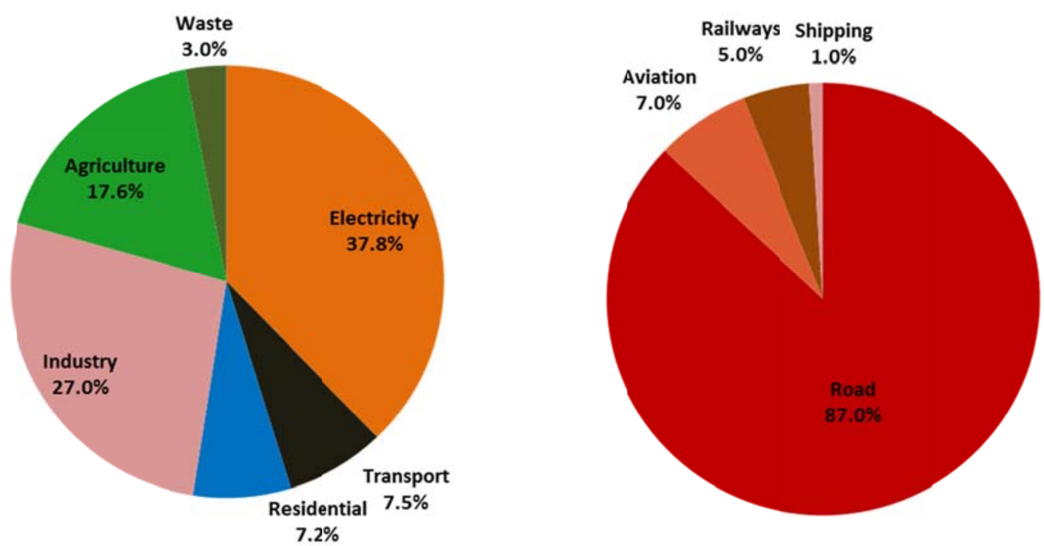
Figure 9: Estimated age mix of fleet based on total vehicle sales in 25 years (current and projected – business as usual scenario)



Road Transport Emissions Outlook

The road transport and aviation sectors account for 4.5 percent of India's gross national product (GDP) and the total transport sector accounts for 7.5 percent of total GHG emissions[19]. The INCCA report for 2007, estimated 142 million tons of CO_2e including emissions from road transport, aviation, rail, and port activity (**Figure 10**). The total commercial energy consumption includes diesel, petrol, coal, kerosene, aviation turbine fuel (ATF), compressed natural gas (CNG), liquefied petroleum gas (LPG), and others. Diesel comprises of the 65 percent of total energy demand in the road transport sector, followed by petrol (24%) and ATF (7%).

Figure 10: Shares of total GHG emissions and transport modes in India in 2007



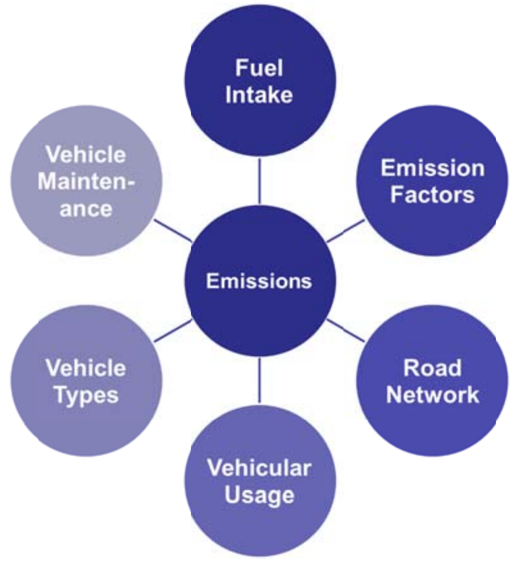
The major economic and population centers have at least doubled their administrative boundaries between 1990 and 2010. This, combined with increasing incomes, has been the impetus for exponential increase in vehicle sales, congestion rates, air pollutant and GHG emissions, and ambient pollution levels. Other emissions related to road transport (such as those from resuspended road dust, and wear of tyres and brake linings) are also an important source of the coarse fraction of PM.

[19] The Indian Greenhouse Gas Emissions Report for 2007, published by the Indian Network for Climate Change Assessment (INCCA), Ministry of Environment and Forests, May 2010.

A listless mix of application of vehicles – to move people and freight, under varying loading conditions, and a vibrant age mix in the on-road vehicle fleet presents a challenging task for estimating the total emissions at the national, state, and city level.

The emissions inventory is built for the following pollutants – particulates in two bins (PM_{10}, $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), black carbon (BC), and Carbon Dioxide (CO_2).

Figure 11: Parameters included in the road transport emissions analysis



We utilized the ASIF methodology [20] to calculate vehicle exhaust emissions. In this method, the parameters are defined in terms of total travel activity (NV), modal shares (S) by mode in vehicle-km traveled (VKT) and appropriate emission factor (EF) in mass pollutant emitted per vehicle-km travelled.

This translates to

$$E_{s,c,v,f,g,p} = \sum_{s,c} \left\{ NV_{v,g} * S_f * VKT_{v,g} * EF_{v,f,g,p} \right\}$$

Where

- $E_{s,c,v,f,g,p}$ denotes total emissions by pollutant, calculated by state, city, vehicle type, fuel type, and by age. The total emissions are calculated at the state and city (as a subset of state) level, and then aggregating to the national level
- $NV_{v,g}$ stands for total number of vehicles on-road by vehicle types and by age. It is assumed 60-70 percent of the registered fleet is considered on-road per year. The vehicle numbers by age is deduced from the vehicle sales at the national level
- S_f stands for share of vehicles on-road by fuel type for each vehicle type
- $VKT_{v,g}$ stands for annual average vehicle kilometers traveled by vehicle type and by age. It is assumed that annual vehicle usage reduces by age for all categories[21]

[20] Schipper, L., Marie-Lilliu, C., Gorham, R., 2000. "Flexing the link between transport and greenhouse gas emissions: A path for the World Bank", International Energy Agency, Paris, France.

[21] Ekbordin and Tami et al

$EF_{v,f,g,p}$ stands for fleet average emission rate by vehicle type, fuel type, age group, and by pollutant

s = state; c= city; v = vehicle; f = fuel; g = age group; p = pollutant

Table 2: Summary of previous studies on road transport emissions

	Study year	Pollutants covered	Calculation method
ADB, 2006	2005	PM	3
Bidya an Broken, 2009	2005	PM, NOx, CO, SO2, VOC, CO2	3
Garg et al., 2006	2005, 2000, 1995, 1990	PM, NOx, CO, SO2, CO2	1
Fulton and Eads, 2004	2005	PM, NOx, CO, SO2, VOC, CO2	2
IIASA, 2008	2005, 2000, 1995, 1990	PM, NOx, SO2, CO2	1
Van Ardenne et al., 2005	2000	NOx, CO, SO2, VOC, CO2	1
Singh et al.,2008	2000, 1980	NOx, CO, VOC, CO2	1
Borken et al. 2007	2000	PM, NOx, CO, SO2, VOC, CO2	2
OHara et al, 2007	2000	NOx, CO, SO2, VOC, CO2	1
Mittal and Sharma 2003	1997	PM, CO, SO2, VOC, CO2	2
Oliver et al, 2002	1995, 1990	NOx, CO, SO2, VOC, CO2	1
Ramanathan & Parikh, 1999	1994	PM, CO, VOC, CO2	2
MiEF, 2004	1994	CO2	1
Bhattacharya & Mitra, 1998	1994, 1990	CO, VOC, CO2	1V
Sahu et al., 2012	1990-2000	NOx	3
This work	2010-30	PM, NOx, CO, SO2, VOC, BC, CO2	3

This table is reproduced from Bidya and Broken (2009) with permission from Broken (IIASA)
Method: 1 - fuel consumption and total roads; 1V - fuel consumption and vehicle category;
2 – Vehicle kilometer and vehicle category; 3 - vehicle kilometer and vehicle sub category.

The average VKT and average trip lengths by mode are estimated from passenger travel surveys conducted for the Ministry of Urban Transport and secondary sources from literature review. The age mix of on-road vehicles (presented in **Figure 9**) was supplemented with data from the "pollution under check" (PUC) program, under which all passenger and para-transit vehicles are required to undergo emission tests and receive an inspection and maintenance certificate. We did not utilize the emission rate results from PUC tests, as they are based on free-acceleration tests conducted along the road-side for compliance and do not include a full driving cycle. We used emission factors for the Indian vehicle fleet by CPCB (2010) and integrated with DIESEL (2008) and GAINS (2010)[22]. For the projected years, a gradual introduction of newer emission standards is assumed between 2014 and 2030, which will affect the emission rates for the newer fleet and subsequently the fleet in the consequent years. A deterioration rate for older fleet for all passenger and freight vehicles is also assumed[23].

[22] CPCB (2010) – Vehicular source emission factors and profiles, Central Pollution Control Board (India) @ http://cpcb.nic.in/Source_Apportionment_Studies.php
GAINS (2010) - Greenhouse Gas and Air Pollution Interactions and Synergies , IIASA (Austria) @ http://gains.iiasa.ac.at/index.php/home-page
DIESEL (2008) – Developing integrated emission strategies for existing land-transport, PCD (Thailand) & The World Bank (USA) @ http://cleanairinitiative.org/portal/projects/DIESEL

[23] Based on the results presented by ARAI (Pune, India), as part of CPCB's source apportionment and emissions inventory studies in six Indian cities @ http://cpcb.nic.in/Source_Apportionment_Studies.php

In India, vehicle emission standards exist for hydrocarbons (HC), NO_x, CO and in the case of diesel fueled vehicles, PM. Vehicle standards were mandated as late in year 2010 - in response to the recommendations by the Mashelkar committee[24]. The Bharat Standards are based on the Euro standards for vehicle emissions, except for 2 and 3 wheelers (standards of which are based on standards unique to the Indian context). Bharat IV standards were initially mandated for 13 cities, while the rest of the country had to comply with Bharat III standards. Over time more cities have been added to the Bharat IV list and is set to go up to 50 cities by 2015. However, with differing standards and fuel qualities, vehicles that are designed for higher standards will emit more pollution if fueled with a lower quality fuel. Given the large-scale movement of commercial vehicles in particular - this poses a genuine problem. The sulfur content in fuel in India is higher than international standards and is on par with that of China (150 ppm for petrol, 350 ppm for diesel). In addition, adulteration of fuel is a significant issue that has a major impact on air pollution[25].

Table 3: Summary of emission standards in India (g/kwh)

	Bharat 3	**Bharat 4**	**Bharat 5**	**Bharat 6**
	CO/NOx/HC/PM/HC+NOx			
LDV Petrol	2.3/0.15/0.2/-/-	1.0/0.08/0.1/-/-	1.0/0.06/0.1/0.005/-	1.0/0.06/0.1/0.005/-
LDV Diesel	0.64/0.5/-/0.1/0.56	0.5/0.25/-/0.025/0.3	0.5/0.18/-/0.005/0.23	0.5/0.08/-/0.0045/0.17
HDV Diesel	2.1/0.5/0.66/0.1/-	1.5/3.5/0.46/0.02/-	1.5/2.0/0.46/0.02/-	1.5/0.4/0.13/0.01/-
2-Wheelers	1.0/-/-/-/1.0	-/-/-/-/-	-/-/-/-/-	-/-/-/-/-
3-Wheelers Petrol	1.25/-/-/-/1.25	-/-/-/-/-	-/-/-/-/-	-/-/-/-/-
3-Wheelers Diesel	0.5/-/-/0.5/0.5	-/-/-/-/-	-/-/-/-/-	-/-/-/-/-

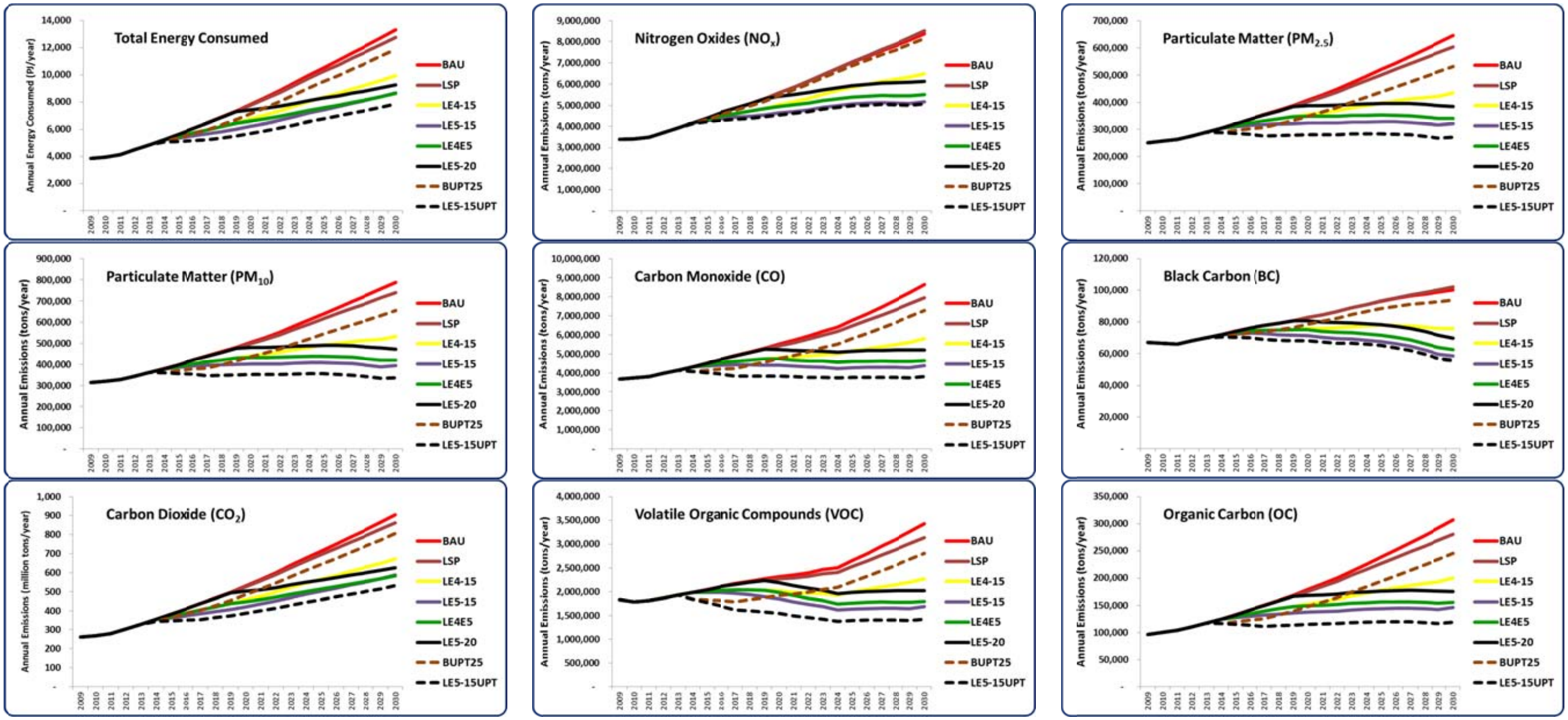
A summary of results from business as usual and assumed “what-if” scenarios is presented in **Figure 12** for each of the pollutants. A summary of the total emissions by state is presented in **Table 4** for 2010, **Table 5** for 2030 business as usual, and **Table 6** for one of the scenarios for 2030 which includes assumed lower sales projection, advanced emission standards, and an aggressive urban transport policy.

Emissions from the transport sector are a result of multiple factors - including but not limited to, vehicle fuel standards, badly maintained roads and public transport vehicles, lack of transportation options and urban planning, adulterated fuel, aging fleet, and freight movement. There cannot be a silver bullet to address this issue and one cannot have an impact on emissions from transport using only one policy instrument. For instance improving vehicle standards by itself will not reduce pollution, unless it is accompanied by a host of other complementing policies.

[24] Auto Fuel Policy report by Mashelkar Committee, the Government of India @ http://petroleum.nic.in/autopolicy.pdf

[25] A full summary of evolution of emission standards and comparisons to developed countries is presented by ICCT (2012) – Contact: Dr. Micahel Walsh: MPWALSH@igc.org

Figure 12: Estimated energy and emissions outlook for the road transport in India



The scenarios are designated as follows: (a) BAU = business as usual growth rate and no change in the emission standards (b) LSP = lower sales projection and no change in the emission standards (c) LE4-15 = lower sales projection with Bharat 4 standards for all vehicles by 2015 for all states (d) LE5-15 = lower sales projection with Bharat 5 standards for all vehicles by 2015 for all states (e) LE5-20 = lower sales projection with Bharat 5 standards for all vehicles by 2020 for all states (a delayed introduction of the standards) (f) LE4E5 = lower sales projection with Bharat 4 enforced in 2015and Bharat 5 standards introduced in 2020 for all vehicles and for all states (g) BUPT25 = business as usual with no change in emission standards, with an aggressive urban passenger transport policy to promote public transport and NMT, in order to reduce 25 percent of the vehicle km traveled from passenger vehicles (h) LE5-15UPT = lower sales projections with introduction of Bharat 5 standards by 2015 and an aggressive urban passenger transport policy.

Table 4: Total emissions from road transport in India by State for 2010 (base year)

	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Andhra Pradesh	19,380	1,550	224,740	278,830	130,700	18.7	4,580
Arunachal Pradesh	130	20	2,090	1,620	570	0.2	40
Assam	5,110	770	90,570	69,540	27,280	6.5	1,640
Bihar	5,240	520	71,030	75,110	32,870	5.2	1,450
Chattishgarh	5,120	700	85,910	67,850	36,580	5.8	1,510
Goa	1,860	270	29,690	26,330	11,940	2.3	550
Gujarat	23,330	2,200	276,450	345,740	169,470	22.5	5,680
Haryana	12,640	1,760	221,540	178,310	77,680	14.9	3,910
Himachal Pradesh	2,010	360	38,040	28,770	9,950	3.0	710
Jammu and Kashmir	2,630	390	44,260	34,860	13,050	3.4	860
Jharkhand	6,100	860	93,910	85,680	39,210	7.2	1,780
Karnataka	16,160	1,380	217,470	237,050	107,180	17.7	4,350
Kerala	15,910	1,330	123,030	211,930	78,750	13.4	3,700
Madhya Pradesh	9,620	700	130,400	143,330	84,900	8.8	2,400
Maharashtra	33,690	3,210	379,440	490,800	226,810	32.8	8,210
Manipur	490	70	7,520	6,350	2,810	0.6	150
Meghalaya	870	150	16,430	11,730	3,610	1.2	310
Mizoram	250	40	3,330	3,650	1,130	0.4	80
Nagaland	2,190	390	45,060	28,800	8,880	3.2	800
Orissa	6,480	850	94,340	90,340	45,330	7.2	1,810
Punjab	9,220	970	143,800	133,650	73,380	9.3	2,490
Rajasthan	14,530	1,530	213,540	203,520	101,920	15.1	4,050
Sikkim	170	40	3,010	2,330	580	0.3	70
Tamil Nadu	25,500	2,690	346,180	375,120	199,790	28.5	6,590
Tripura	720	80	8,400	9,150	3,420	0.7	190
Uttarakhand	1,540	190	19,850	22,810	11,590	1.6	410
Uttar Pradesh	15,910	1,350	192,030	240,420	149,120	13.7	3,570
West Bengal	9,620	1,400	186,560	136,980	59,030	12.9	3,150
UNION TERRITORYS							
Andaman & Nicobar	180	20	2,210	2,380	1,080	0.2	50
Chandigarh	680	70	4,820	13,660	7,990	0.7	110
Dadra & Nagar Haveli	260	50	5,430	3,690	1,420	0.4	90
Daman & Diu	170	30	2,510	2,500	1,070	0.3	50
Delhi	7,910	150	59,200	166,590	65,550	10.9	1,120
Lakshadweep	20	10	90	220	110	0.1	10
Puducherry	830	100	9,240	12,470	7,550	0.9	190
Total	**256,270**	**26,040**	**3,391,940**	**3,741,910**	**1,792,120**	**268.8**	**66,490**

All totals in tons/year, except for CO2 in million tons/year

Year 2010 is considered the base year for all the calculations presented in this report. The emission projection data is available for all the intermediate years between 2010 and 2030, but not presented in this report. This is available up on request.

Table 5: Total emissions from road transport in India by State for 2030 Business as usual scenario

	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Andhra Pradesh	47,670	4,580	546,250	596,970	243,600	60.6	6,500
Arunachal Pradesh	240	60	5,450	3,580	1,130	0.5	70
Assam	9,400	2,170	227,710	154,760	53,280	18.9	2,190
Bihar	12,100	1,640	168,300	153,190	61,600	17.2	2,100
Chattishgarh	13,330	2,040	215,160	163,010	71,930	17.7	2,540
Goa	4,170	760	75,660	63,810	23,480	7.0	800
Gujarat	59,470	6,850	666,190	748,160	317,730	76.8	8,130
Haryana	25,720	5,240	530,940	417,340	149,340	46.6	5,160
Himachal Pradesh	3,490	1,030	95,120	63,790	19,810	8.8	930
Jammu and Kashmir	5,600	1,160	115,990	82,880	26,740	10.4	1,460
Jharkhand	13,240	2,560	234,420	189,210	75,090	22.2	2,370
Karnataka	42,190	4,220	557,300	552,380	210,440	58.7	7,560
Kerala	36,020	4,710	340,200	400,750	143,950	49.4	6,450
Madhya Pradesh	27,920	2,070	290,900	334,550	159,570	29.1	3,460
Maharashtra	83,300	10,730	947,980	1,085,300	427,140	116.6	12,270
Manipur	1,180	230	20,070	15,500	5,690	2.0	260
Meghalaya	1,430	440	41,980	26,760	7,400	3.7	440
Mizoram	490	140	8,690	8,010	2,230	1.2	120
Nagaland	3,140	1,080	114,060	62,170	17,930	9.0	1,030
Orissa	15,550	2,550	232,690	198,290	86,240	22.2	2,560
Punjab	23,740	2,970	334,500	326,660	139,680	30.3	3,450
Rajasthan	36,790	4,900	516,560	473,190	195,550	50.8	6,350
Sikkim	310	100	7,930	5,450	1,290	0.9	110
Tamil Nadu	71,190	8,140	883,480	901,550	388,940	92.9	10,700
Tripura	1,360	240	21,780	16,600	6,230	2.2	270
Uttarakhand	3,980	570	48,110	54,070	22,070	5.4	590
Uttar Pradesh	49,030	4,600	434,170	596,130	280,800	50.7	5,370
West Bengal	19,700	3,810	469,260	338,360	118,540	37.7	4,380
UNION TERRITORYS							
Andaman & Nicobar	420	70	5,830	5,570	2,090	0.7	80
Chandigarh	2,700	280	12,660	46,090	15,920	3.6	230
Dadra & Nagar Haveli	440	130	13,540	8,920	2,840	1.1	120
Daman & Diu	380	80	6,350	6,380	2,110	0.7	70
Delhi	27,200	690	158,170	498,490	132,750	46.5	1,990
Lakshadweep	50	10	250	380	200	0.1	10
Puducherry	2,690	320	24,310	33,390	14,750	3.1	350
Total	**645,440**	**80,980**	**8,371,770**	**8,631,480**	**3,427,870**	**903.5**	**100,320**

All totals in tons/year, except for CO2 in million tons/year

Year 2010 is considered the base year for all the calculations presented in this report. The emission projection data is available for all the intermediate years between 2010 and 2030, but not presented in this report. This is available up on request.

Table 6: Total emissions from road transport in India by State for 2030 LE5-15UPT scenario (best feasible scenario to reach levels of 2010)

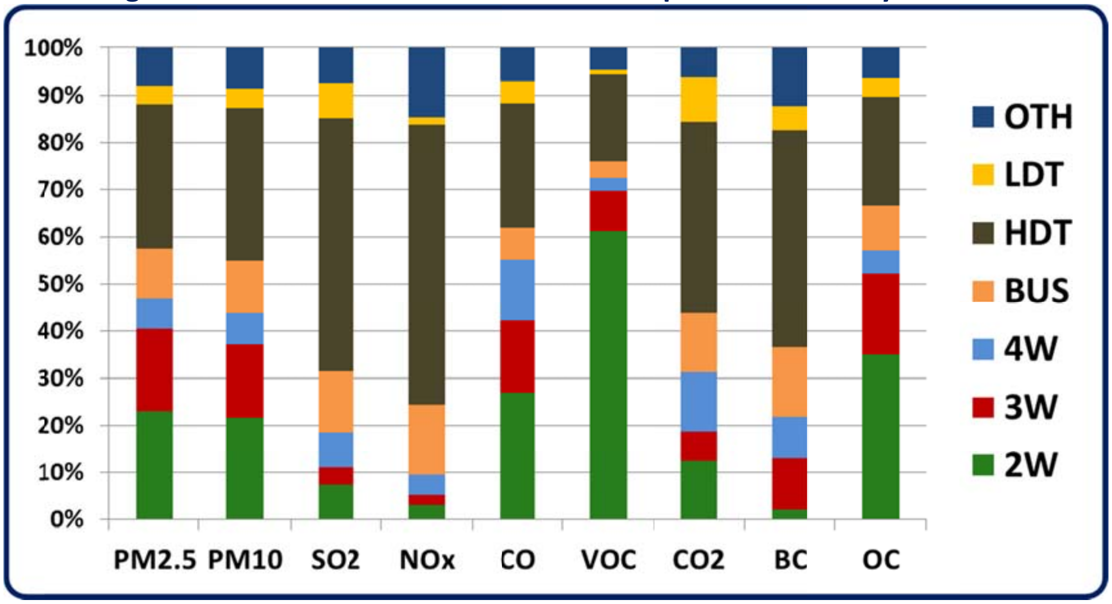
	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Andhra Pradesh	19,840	2,880	331,130	266,390	99,840	36.4	3,580
Arunachal Pradesh	120	40	3,340	1,820	580	0.3	40
Assam	4,590	1,420	143,390	79,550	26,680	12.0	1,310
Bihar	5,180	990	101,780	69,770	26,340	10.1	1,160
Chattishgarh	6,050	1,350	133,440	79,600	31,740	11.5	1,510
Goa	1,880	490	46,960	29,940	10,610	4.3	470
Gujarat	24,060	4,170	401,120	321,030	127,850	44.3	4,430
Haryana	11,790	3,280	331,980	201,410	69,850	28.1	3,040
Himachal Pradesh	1,780	670	59,750	33,020	10,300	5.6	560
Jammu and Kashmir	2,780	770	70,890	40,640	13,110	6.7	850
Jharkhand	5,830	1,610	146,270	91,290	33,810	13.6	1,370
Karnataka	18,410	2,690	333,160	243,690	88,410	35.6	4,230
Kerala	15,020	2,800	188,490	163,240	57,660	28.5	3,250
Madhya Pradesh	11,130	1,260	177,390	143,150	62,570	16.7	1,950
Maharashtra	33,810	6,300	561,960	458,290	172,760	66.0	6,480
Manipur	540	140	12,100	7,290	2,590	1.2	150
Meghalaya	750	280	26,060	13,860	4,080	2.3	260
Mizoram	220	80	5,070	3,520	1,030	0.7	70
Nagaland	1,760	710	72,320	35,160	10,610	5.8	630
Orissa	6,700	1,610	144,400	93,880	37,190	13.7	1,480
Punjab	9,880	1,810	207,240	146,090	58,350	17.7	2,000
Rajasthan	15,740	2,970	313,570	213,520	82,750	30.0	3,560
Sikkim	170	60	4,740	2,660	710	0.5	60
Tamil Nadu	29,870	5,170	537,910	399,080	159,100	56.4	6,080
Tripura	610	150	13,250	8,070	2,890	1.4	150
Uttarakhand	1,630	350	29,120	23,060	8,940	3.1	330
Uttar Pradesh	18,790	2,610	259,680	240,440	106,360	27.6	2,900
West Bengal	9,530	2,550	296,060	169,810	57,670	24.0	2,670
UNION TERRITORYS							
Andaman & Nicobar	180	40	3,490	2,450	900	0.4	40
Chandigarh	950	140	6,120	14,960	5,340	1.7	110
Dadra & Nagar Haveli	230	90	8,660	4,680	1,500	0.7	70
Daman & Diu	170	50	3,890	2,800	930	0.5	40
Delhi	10,500	330	80,520	188,070	46,170	25.0	840
Lakshadweep	20	10	140	150	70	0.1	10
Puducherry	1,060	200	14,270	13,280	5,590	1.8	190
Total	**271,400**	**49,910**	**5,069,500**	**3,805,510**	**1,424,710**	**532.8**	**55,710**

All totals in tons/year, except for CO2 in million tons/year

Year 2010 is considered the base year for all the calculations presented in this report. The emission projection data is available for all the intermediate years between 2010 and 2030, but not presented in this report. This is available up on request.

It is assumed that the actual emissions in 2030 could be anywhere between the red line (BAU) and the dotted black line (LE5-15UPT) in **Figure 12**.

Figure 13: Total emissions from road transport in India for year 2010



2W = 2-wheelers; 3W = wheelers; 4W = 4-wheelers including cars and jeeps; HDT = heavy duty trucks; LDT = light duty trucks; OTH = others including tractors and multi-utility vehicles

Table 7: Total emissions from road transport in India by City for 2010 (base year)

	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Ahmedabad	2,290	45	18,430	40,550	21,540	2.2	400
Bengaluru	5,790	170	75,050	97,490	39,900	7.3	1,530
Bhopal	720	15	6,260	12,800	7,760	0.7	130
Chennai	5,070	150	65,810	82,570	38,470	6.3	1,280
Coimbatore	940	15	5,110	18,010	12,170	0.9	110
Delhi	7,910	135	59,200	166,590	65,550	10.9	1,120
Hyderabad	3,970	90	34,660	74,220	31,920	5.4	690
Indore	1,650	50	21,840	25,680	13,990	1.9	430
Jaipur	2,460	75	34,660	36,510	19,420	2.8	660
Kanpur	880	25	10,630	14,060	8,750	1.0	190
Kochi	780	30	9,740	11,250	3,570	1.2	230
Kolkata	1,120	40	18,990	21,990	5,980	1.8	360
Lucknow	1,060	25	8,000	18,680	12,490	1.0	170
Ludhiana	980	35	18,070	15,910	5,180	1.4	320
Mumbai	2,430	55	20,760	51,310	17,470	3.1	500
Nagpur	1,240	30	11,230	20,120	13,290	1.2	230
Patna	1,010	25	12,550	17,240	7,360	1.1	240
Pune	2,060	70	26,040	29,970	15,390	2.7	530
Surat	1,120	20	5,680	21,510	13,080	0.9	130
Vadodara	1,250	30	11,040	22,130	13,130	1.2	220
Varanasi	620	15	6,220	9,930	6,880	0.6	120
Vishakapatnam	780	20	7,750	13,320	7,550	0.8	160
Total	**46,030**	**1,120**	**487,630**	**821,740**	**380,760**	**55.3**	**9,640**

All totals in tons/year, except for CO2 in million tons/year

Table 8: Total emissions from road transport in India by City for 2030 (business as usual)

	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Ahmedabad	8,630	175	53,500	102,540	43,350	9.2	990
Bengaluru	17,260	540	204,080	246,510	82,570	25.7	3,110
Bhopal	2,730	55	15,960	33,540	15,110	2.8	250
Chennai	15,780	485	179,120	217,360	78,860	22.2	2,610
Coimbatore	4,030	65	12,310	50,710	23,290	3.9	190
Delhi	27,200	595	158,170	498,490	132,750	46.5	1,990
Hyderabad	12,530	300	87,140	187,250	62,040	19.5	970
Indore	4,980	155	55,560	64,760	27,610	6.4	710
Jaipur	7,880	265	94,460	101,330	39,940	10.6	1,410
Kanpur	3,050	85	27,800	38,930	17,300	3.6	360
Kochi	2,260	90	28,750	28,300	8,040	4.0	550
Kolkata	2,530	130	49,980	65,790	13,390	6.5	610
Lucknow	4,340	90	21,080	54,030	24,460	4.4	370
Ludhiana	1,940	110	44,710	41,940	10,800	4.7	470
Mumbai	7,550	210	57,620	133,020	36,150	13.0	960
Nagpur	4,790	115	30,490	54,750	26,120	5.0	500
Patna	2,910	80	33,100	37,480	14,840	3.7	440
Pune	6,400	220	70,780	77,420	31,160	9.3	1,070
Surat	4,550	70	15,380	52,060	25,340	4.1	280
Vadodara	4,600	100	28,960	55,830	25,660	4.8	420
Varanasi	2,330	50	15,320	26,170	13,270	2.2	220
Vishakapatnam	2,750	65	20,750	32,660	14,890	2.9	310
Total	**150,930**	**4,000**	**1,304,910**	**2,200,750**	**766,810**	**213.8**	**18,680**
All totals in tons/year, except for CO2 in million tons/year							

Table 9: Total emissions from road transport in India by City for 2030 (LE5-15UPT)

	PM2.5	SO2	NOx	CO	VOC	CO2	BC
STATES							
Ahmedabad	3,300	105	28,250	37,420	15,390	5.0	510
Bengaluru	7,510	350	117,560	101,930	33,410	15.2	1,710
Bhopal	1,010	35	8,840	12,410	5,340	1.5	130
Chennai	6,730	310	104,110	89,620	31,440	13.1	1,450
Coimbatore	1,390	35	6,150	17,750	7,750	2.0	80
Delhi	10,500	290	80,520	188,070	46,170	25.0	840
Hyderabad	5,030	175	49,750	76,660	22,810	11.4	490
Indore	2,030	100	33,280	27,200	10,920	3.7	400
Jaipur	3,330	165	54,940	41,900	16,060	6.1	770
Kanpur	1,190	50	16,430	15,510	6,550	2.0	200
Kochi	1,100	60	16,070	11,960	3,480	2.5	300
Kolkata	1,170	80	29,030	26,100	5,980	3.6	340
Lucknow	1,540	50	10,990	18,650	8,390	2.2	180
Ludhiana	920	70	27,110	18,400	5,170	2.7	270
Mumbai	2,920	115	29,180	47,770	13,000	6.7	450
Nagpur	1,780	65	16,830	20,170	9,310	2.6	250
Patna	1,210	50	19,390	15,680	5,970	2.1	250
Pune	2,760	140	41,410	32,520	12,480	5.6	600
Surat	1,570	35	7,430	17,640	8,490	2.0	120
Vadodara	1,700	60	16,270	20,780	9,180	2.6	210
Varanasi	870	30	8,860	9,960	4,790	1.2	120
Vishakapatnam	1,060	40	11,840	12,610	5,480	1.6	160
Total	**60,510**	**2,350**	**734,130**	**860,600**	**287,440**	**119.4**	**9,720**
All totals in tons/year, except for CO2 in million tons/year							

The total emissions are further gridded from state and city totals to a spatial resolution of 0.25 degree resolution and an area covering 32 degree in longitude and 32 degree in latitude. The layers of information utilized for gridding these emissions is presented in **Figure 14**. The layers of information includes (a) gridded population at 0.25 degree resolution (b) gridded road density maps for highways, trunk roads, and arterial roads (inter and intra city) (c) activity maps like ports and airports, which are hot spots to freight movement (d) urban center locations, which are hot spots to the passenger travel (e) landuse maps to distinguish between populated, agricultural, mining, and forest areas for designated spatial apportionment of the emissions. Gridded emissions are presented in **Figure 15**.

Figure 14: Layers of information used for spatial gridding of the emissions

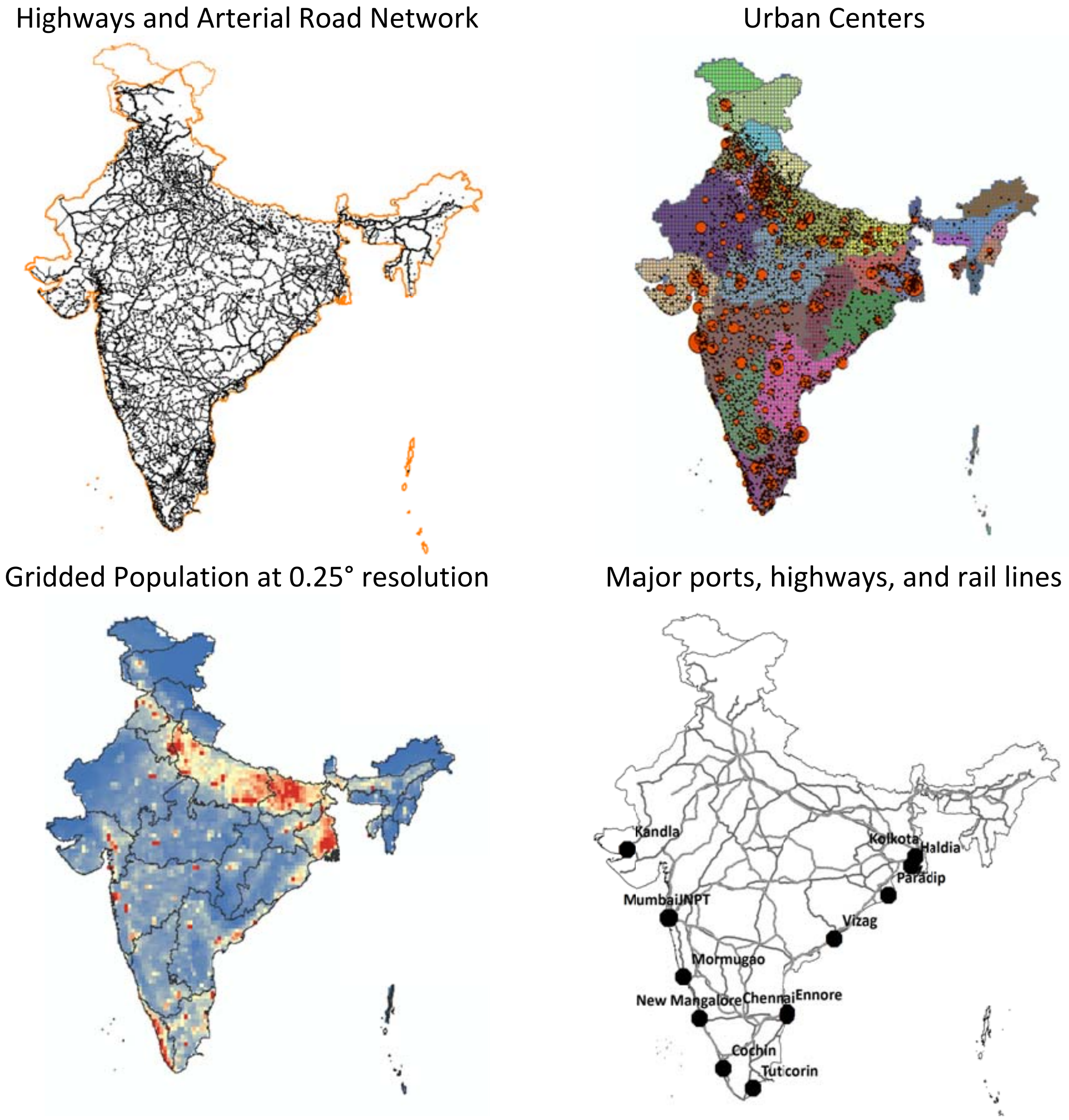
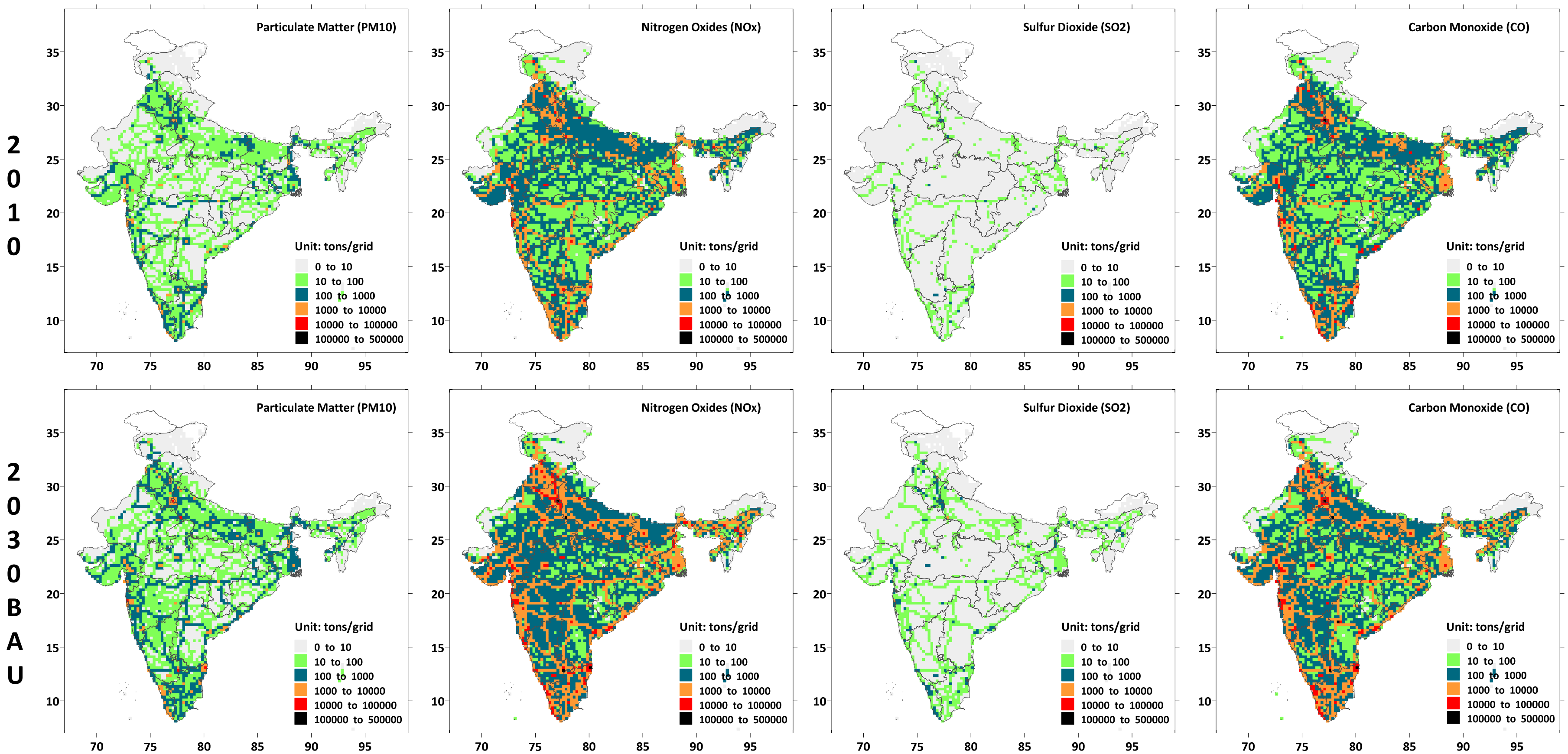


Figure 15: Gridded emissions inventory at spatial resolution of 0.25° resolution

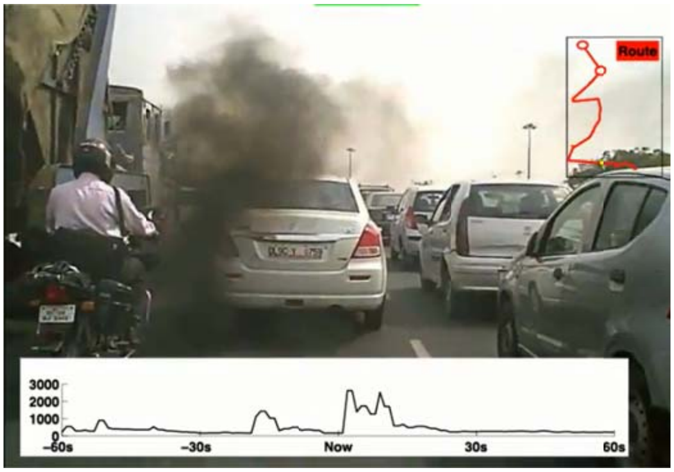


All the maps are presented for the same color scale. The NO_x and CO emissions are traditionally higher from the vehicle exhaust followed by PM and SO_2. The gridded emissions fields are also available for other scenarios which fall between these two scenarios, but not presented in this report. The intensity of the emissions in 2030 and beyond is expected to increase surrounding the urban centers due to the growing passenger travel demand and along the highways due to the growing freight movement between and to the cities.

Health Impacts of Road Transport Emissions

Estimating the health impacts of road transport emissions can be tricky for several reasons; transport accounts for about 30 percent of emissions and overall ambient concentrations in the Indian cities[26], and hence isolating transport sources by itself is tricky and the impacts of air pollution can be indirect on health and manifest itself in non-respiratory impacts that are hard to account for.

Figure 16: Severity of on-road exposure[27]



Air pollution disproportionately affects those most vulnerable – with compromised or still developing immune systems - the sick, elderly and children. In India, those with means travel in cars and use air conditioning indoors, which to a small extent insulates them from chronic exposure to the pollutants. However, people who are directly exposed to pollution on road corridors, or those living along roads bear the brunt of the air pollution. That said, several studies have looked at this issue in particular[28] based on extensive epidemiological and cohort studies to better understand the relationships between ambient PM pollution and various health end points. Drawing from these

[26] A composite of the studies conducted by the Central Pollution Control Board (New Delhi, India) in six cities, for total PM_{10} ambient pollution
@ http://cpcb.nic.in/Source_Apportionment_Studies.php

[27] Full video is available @ http://www.youtube.com/watch?v=JNHhGVeD050
and full report of the study is available @ http://www.ocf.berkeley.edu/~apte/research_dl.html

[28] Brauer et al., "Global burden of disease attributable to outdoor air pollution", published in Env. Sci. & Tech, 2012
@ http://www.dx.doi.org/10.1021/es2025752
Directory of resources on transport, health, and environment in the developing countries by WHO
@ http://www.who.int/heli/risks/urban/transpdirectory/en/index.html
Health effects of transport related air pollution (2005) published by WHO
@ http://www.euro.who.int/en/what-we-publish/abstracts/health-effects-of-transport-related-air-pollution
Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects, Special Report 17, published by the Health Effects Institute (USA) @ http://pubs.healtheffects.org

studies, we use their dose-response functions to estimate the mortality and morbidity impacts on air pollution from road transport in India.

Health impact analysis estimates premature mortality and morbidity as a result of outdoor air pollution, using concentration-response functions. However, this is not as easy to calculate and in all likelihood is a gross underestimate that captures only the direct impacts of air pollution (respiratory illness, allergies etc.). The indirect impacts of exposure to pollutants are many - an increase in inflammation, cardiac conditions, decrease in fertility, cancer, premature birth, among others. We estimate the health impacts (mortality and morbidity) of baseline and future scenarios, using the following the methodology

$$\delta E = \beta * \delta C * \delta P$$

where,

- δE = number of estimated health effects (various end points for mortality and morbidity)
- β = the concentration-response function; which is defined as the change in number of cases per unit change in concentrations per capita. This is established based on epidemiological studies conducted over a period of time, analyzing the trends in hospital records and air pollution monitoring
- δC = the change in concentrations; although, the World Health Organization claims that there is no threshold over which the health impacts are measured. In this study, since we are evaluating pollution from transport emissions only, no threshold value is assumed
- δP = the population exposed to the incremental concentration; defined as the vulnerable population, of age more than 17 years, who spend more time outdoors. This spatial spread of population is obtained from GRUMP (2010) and Census-India (2011).

The concentration-response function (β) (CRF) is defined as the change in number of cases per unit change in concentrations per capita. Health effects range from minor irritation in eyes and upper respiratory system to chronic respiratory disease, heart disease, lung cancer, and lead up to premature death. In case of mortality, CRF is set to 0.225% per 10 $\mu g/m^3$ increase in the PM_{10} concentrations (HEI, 2010) as the lower bound[29] and 0.6% per 10 $\mu g/m^3$ increase in the PM_{10} concentrations (WHO, 2005) as the higher bound[30]; the total death incidence rate of 241 per 1,000 people was adjusted for the those due to lower and upper respiratory illnesses (including bronchitis and asthma) and cardio vascular diseases. Among the reported number of deaths, these causes account for 15 percent of the annual death rate (DoES, 2010)[31]. We also

[29] Public Health and Air Pollution in Asia (PAPA): A Multicity Study of Short-Term Effects of Air Pollution on Mortality. Health Effects Institute (2010) @ http://pubs.healtheffects.org/view.php?id=348

[30] Health effects of transport related air pollution (2005) published by WHO @ http://www.euro.who.int/en/what-we-publish/abstracts/health-effects-of-transport-related-air-pollution

[31] Annual Report (2010) on "Registration of Births and Deaths in India". Directorate of Economics and Statistics, the Government of Delhi, New Delhi, India.

estimate morbidity in terms of asthma cases, chronic bronchitis, hospital admissions, and work days lost.

The following assumptions are applied in this study (a) that the concentration-response to changing air pollution among residents is similar to those of residents where the epidemiological studies were performed (b) that the population baseline health status in various states is similar to those observed at the national level (CBHI, 2010)[32] and (c) that the public health status of people in year 2030 remains the same as in year 2010. CRF's for mortality and morbidity are summarized in **Table 10**.

Table 10: Concentration-response functions (in effects per capita per μg/m^3 change in PM concentrations)

Health impact	Effects/capita/(μg/m^3)
Premature mortality (lower bound)	0.0000083
Premature mortality (higher bound)	0.0000220
Adult Chronic Bronchitis	0.00004
Child Acute Bronchitis	0.000544
Respiratory Hospital Admission	0.000012
Cardiac Hospital Admission	0.000005
Emergency Room Visit	0.000235
Asthma Attacks	0.0029
Restricted Activity Days	0.03828
Respiratory Symptom Days	0.183

The population exposed (δP) is defined as the total population exposed to the incremental concentrations (δC) in each grid cell. The grid level population is estimated using GRUMP (2010) and Census-India (2012) and presented in **Figure 14**. The population data and the concentrations of PM_{10} are available at 0.25° resolution.

Particulate Concentration Maps

We used the Comprehensive Air Quality Model with Extensions (CAMx), which is an Eulerian photochemical dispersion model that allows for integrated assessments of gaseous and particulate air pollution over many scales ranging from sub-urban to continental. This model is designed to unify all of the technical features required of "state-of-the-science" air quality models into a single open-source system that is computationally efficient, easy to use, and publicly available[33]. For the analysis of the road transport emissions in India, the CAMx model is set up to model the concentrations for the domain ranging from 7° to 39° in latitudes and 37° to 99° in longitudes at 0.25° resolution. The vertical resolution of the model extends to 12km stretched over 23 layers. The removal processes in the model include dry deposition varying

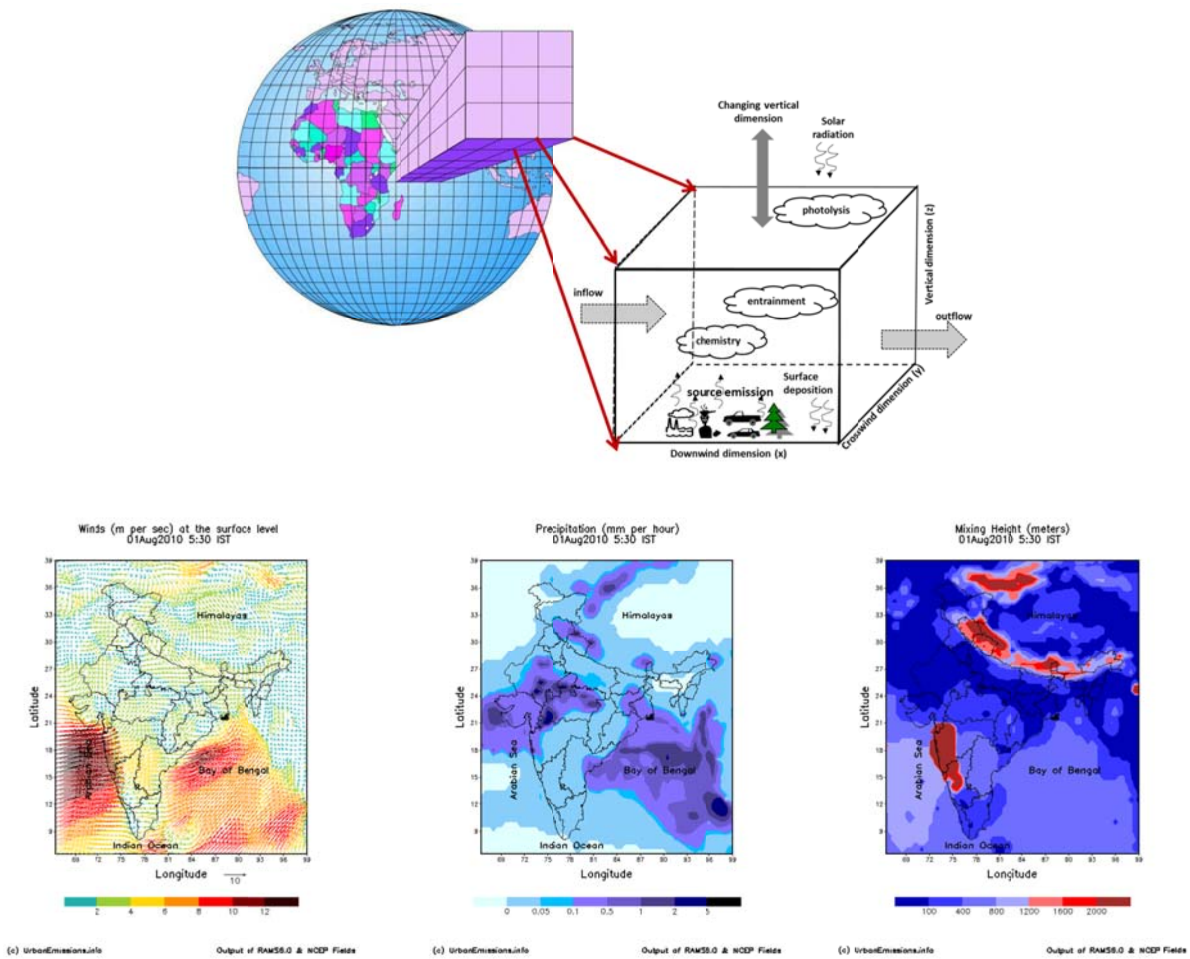
[32] National Health Profile (2010), Central Bureau of Health Intelligence (CBHI), the Government of India, New Delhi, India @ http://www.cbhidghs.nic.in

[33] The CAMx model source code, support systems, manuals, and test cases are available for download @ http://www.camx.com/about/default.aspx

with the landuse patterns and wet deposition due to predominant meteorological conditions. The schematics of the Eulerian modeling system and the model domain are presented **Figure 17**.

The meteorological data (3D wind, temperature, and pressure, as well as surface heat flux and precipitation fields) is derived from the National Center for Environmental Prediction (NCEP) global reanalysis[34]. The NCEP databases are available for the period of 1948 to 2012. We selected 2010 as the base year and the required data fields are processed for this year. The same meteorology for 2010 is used for all the future scenarios. The NCEP global meteorological fields are processed through the RAMS meteorological model (version 6.0)[35] and the data is available at 2 hour interval for the parameters necessary to run the CAMx dispersion model[36].

Figure 17: 3D-Eulerian dispersion model schematics and sample of meteorological fields

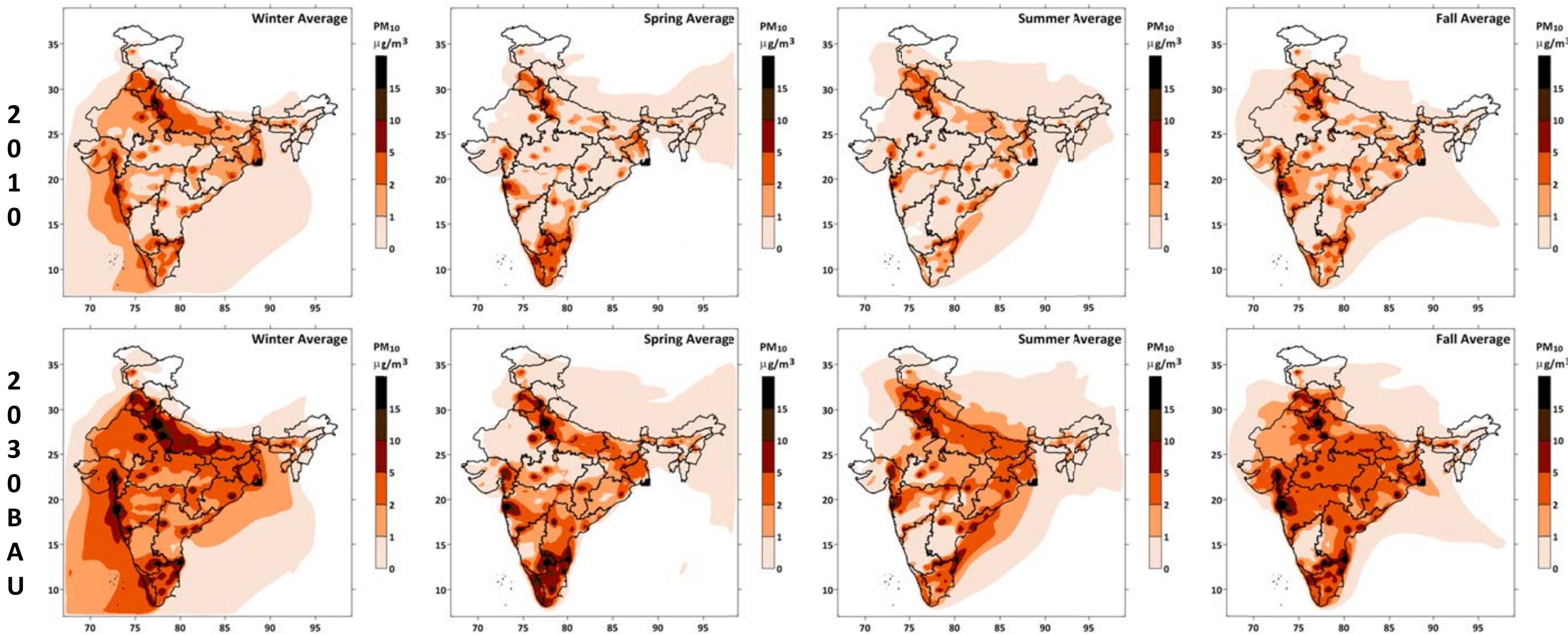


[34] The meteorological fields are available for free @ http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

[35] The RAMS v6.0 model source code, support systems, manuals, and test cases are available for download @ http://www.atmet.com

[36] All the animations are available @ http://www.urbanemissions.info/india-meteorology

Figure 18: Modeled PM_{10} concentration (in $\mu g/m^3$)due to road transport emissions (by season)



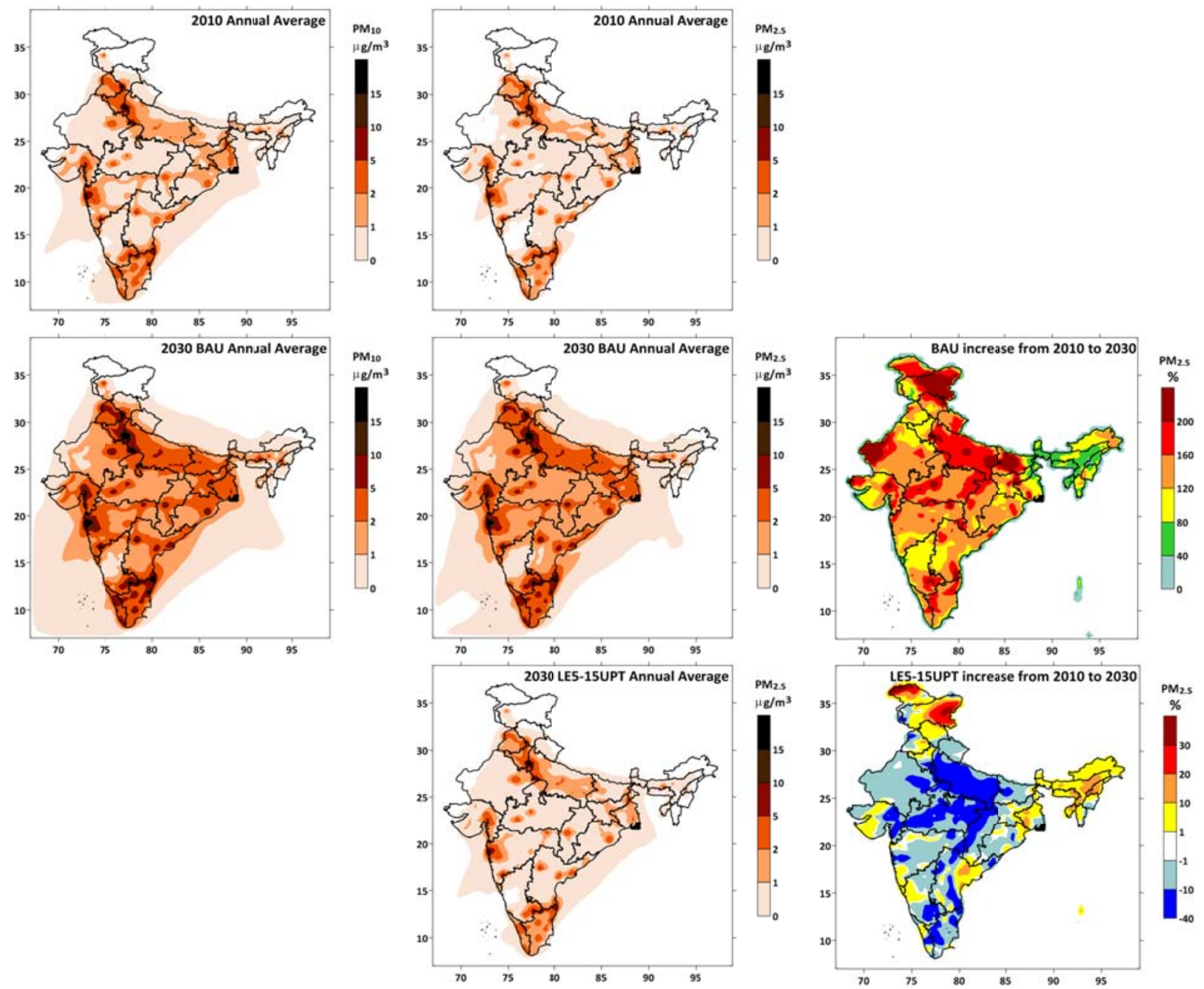
The total PM_{10} concentrations presented in **Figure 18** includes both the coarse and fine fractions ($PM_{2.5}$) and secondary contributions from SO_2 and NO_x emissions. Since, the SO_2 emissions from road transport are very small compared to sectors like power plant and industries, where coal combustion is predominant, the secondary contributions in the transport sector are small.

The concentration maps under the BAU scenario are presented in this report. The same **i**s also available for LE5-15UPT, the most feasible scenario with the highest benefits – which is expected to drop the concentrations in 2030 to the levels of 2010.

The incremental change in the annual average $PM_{2.5}$ concentrations (δC) utilized for the final health impacts analysis. To avoid double counting of health impacts, all the health impacts are calculated for $PM_{2.5}$ fraction only, which includes the secondary contributions from SO_2 and NO_x emissions.

The PM concentrations are modeled in two bins for two reasons (a) most of the measurements available in India are for PM_{10} and this fraction is still the default benchmark for regulatory purposes. Only a handful of cities measure $PM_{2.5}$, even though it is now designated as a criteria pollutant (since November 2009) (b) the epidemiological studies conducted and currently underway are still using PM_{10} as the key indicator, partly due to the reason stated above. For comparative purposes, annual averages for PM_{10} and $PM_{2.5}$ are presented in **Figure 19**. In general, the $PM_{2.5}$ concentrations calculated are 75 percent of the total PM_{10} concentrations.

Figure 19: Modeled annual average concentrations due to road transport emissions



For the percent change maps, the highs of 200 percent over the mountainous Northern territory and the western desert regions, where very limited road transport is present, is a mathematical anomaly and the actual concentrations are very small. The scenario LE5-15UPT is assumed to put the emissions and pollution levels in 2030 back at 2010 levels (blue shades in the last panel).

For all emissions (besides road transport), the national annual average standard for $PM_{2.5}$ is 40 $\mu g/m^3$, for PM_{10} is 60 $\mu g/m^3$. The WHO guideline for $PM_{2.5}$ is 10 $\mu g/m^3$ and for PM_{10} is 15 $\mu g/m^3$.

The total health impacts are calculated using the equation presented earlier in the Chapter, which can now be schematically represented as follows.

Figure 20: Schematics of health impacts assessment

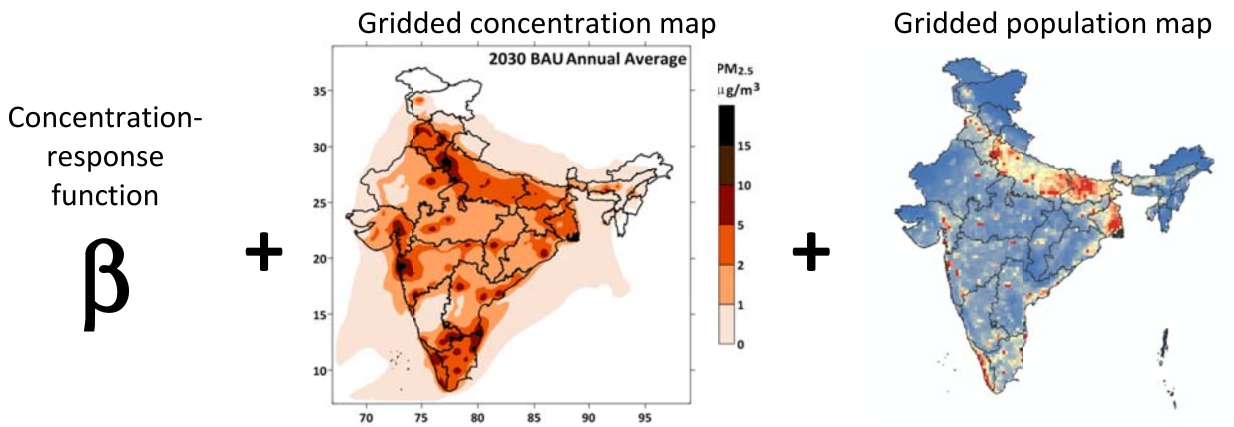
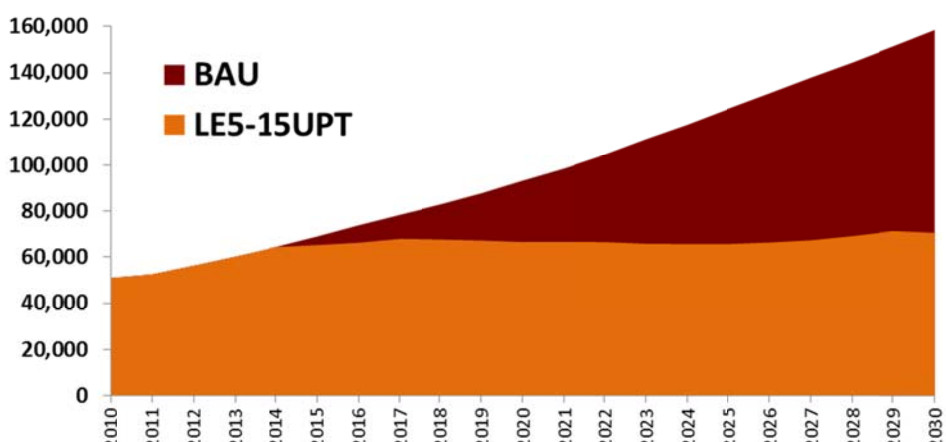


Table 11: Health impacts of road transport emissions in India (numbers rounded)			
	2010	**2030 BAU**	**2030 LE5-15UPT**
Total population (billion)	1.2	1.5	1.5
Mortality			
Premature mortality (lower bound)	18,500	59,500	26,500
Premature mortality (higher bound)	49,500	158,500	70,500
Morbidity			
Adult Chronic Bronchitis	60,000	190,000	85,000
Child Acute Bronchitis	430,000	1,370,000	610,000
Respiratory Hospital Admission	30,000	90,000	40,000
Cardiac Hospital Admission	8,000	24,000	11,000
Emergency Room Visit	0.6	1.7	0.8
Asthma Attacks	6.5	20.9	9.3
Restricted Activity Days (million)	55.8	178.7	79.2
Respiratory Symptom Days (million)	266.4	854.3	378.3

Figure 20: Premature mortality per year (higher bound) due to road transport emissions



The health impacts of air pollution from the transport sector are not insignificant – and the nature of the issue is that those areas with the most population density are most affected. The only way we can have a real impact on air pollution and GHG emissions from the transport sector is by addressing the issue on multiple fronts. Policy measures implemented in isolation, without a multipronged approach will not work. For example, setting fuel efficiency standards and enforcing them is important, but will work only if, among other conditions, roads are also maintained, traffic bottlenecks are eased through traffic management, vehicles maintenance is promoted, and the fuel used is unadulterated. Unless behavioral change gets people to use more public and non-motorized transport, emissions will continue to be a big issue. This will require a concerted and coordinated effort between multiple stakeholders like individuals, industry, and the government. The government needs to provide resources towards public transport to implement policies that fall outside the purview of transport (for instance urban zoning) and the industries can provide incentives to employees to spur the use of public transport.

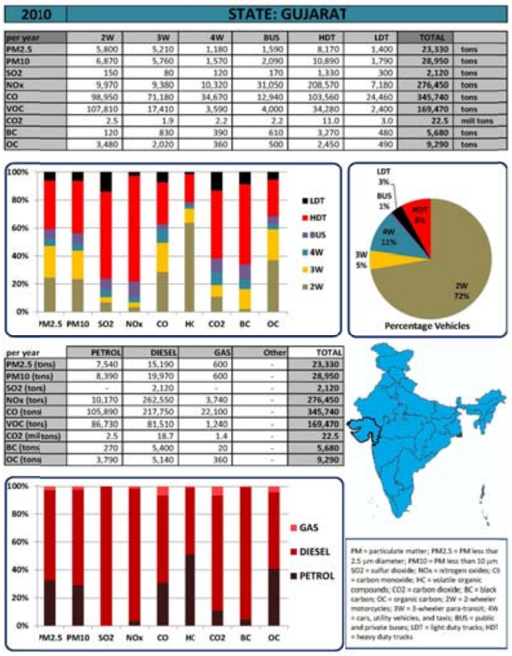
Unless air pollution is addressed on multiple fronts in conjunction with one another, it will continue to be a significant issue for health impacts on population and GHG emissions for climate policy.

"A developed country is not a place where the poor have cars. It's where the rich use public transportation." Enrique Penãlosa, Mayor of Bogota, Columbia

Annex Material

The emission totals by vehicle type and fuel type, and by State and City are available online @ http://www.urbanemissions.info

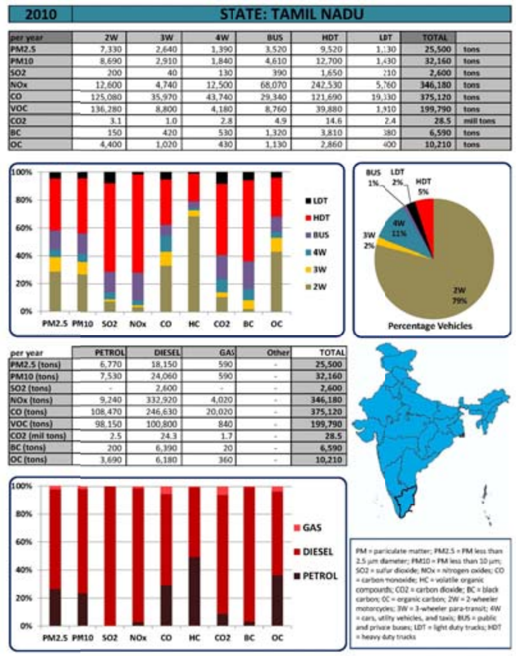
Sample sheets for States and Cities



2010 — STATE: GUJARAT

per year	2W	3W	4W	BUS	HDT	LDT	TOTAL	
PM2.5	5,800	5,210	1,180	1,590	8,170	1,400	23,330	tons
PM10	6,870	5,760	1,570	2,090	10,890	1,790	28,950	tons
SO2	150	80	120	170	1,330	300	2,120	tons
NOx	9,970	9,380	10,320	31,050	208,570	7,180	276,450	tons
CO	98,950	71,180	34,670	12,940	103,560	24,460	345,740	tons
VOC	107,810	17,410	3,590	4,000	34,280	2,400	169,470	tons
CO2	2.5	1.9	2.2	2.2	11.0	3.0	22.5	mill tons
BC	120	830	390	610	3,270	480	5,680	tons
OC	3,480	2,020	360	500	2,450	490	9,290	tons

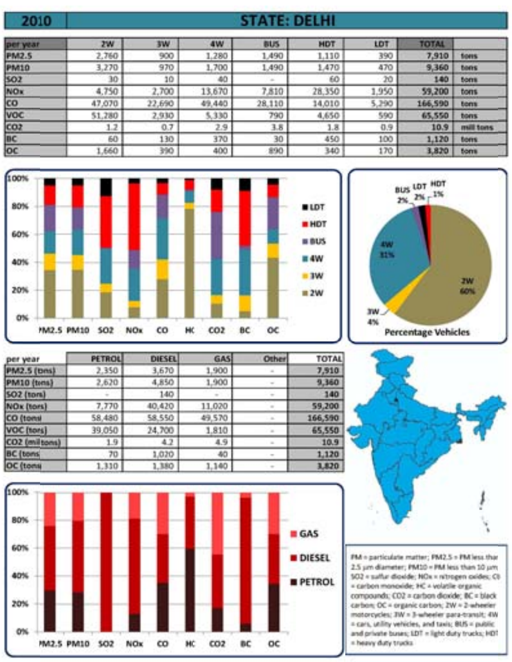
per year	PETROL	DIESEL	GAS	Other	TOTAL
PM2.5 (tons)	7,540	15,190	600	-	23,330
PM10 (tons)	8,390	19,970	600	-	28,950
SO2 (tons)	-	2,120	-	-	2,120
NOx (tons)	10,170	262,550	3,740	-	276,450
CO (tons)	105,890	217,750	22,100	-	345,740
VOC (tons)	86,730	81,510	1,240	-	169,470
CO2 (mil tons)	2.5	18.7	1.4	-	22.5
BC (tons)	270	5,400	20	-	5,680
OC (tons)	3,790	5,140	360	-	9,290



2010 — STATE: TAMIL NADU

per year	2W	3W	4W	BUS	HDT	LDT	TOTAL	
PM2.5	7,330	2,640	1,390	3,520	9,520	1,130	25,500	tons
PM10	8,690	2,910	1,840	4,610	12,700	1,430	32,160	tons
SO2	200	40	130	390	1,650	210	2,600	tons
NOx	12,600	4,740	12,500	68,070	242,530	5,760	346,180	tons
CO	125,080	35,970	43,740	29,340	121,690	19,130	375,120	tons
VOC	136,280	8,800	4,180	8,760	39,880	1,910	199,790	tons
CO2	3.1	1.0	2.8	4.9	14.6	2.4	28.5	mill tons
BC	150	420	530	1,320	3,810	380	6,590	tons
OC	4,400	1,020	430	1,130	2,860	400	10,210	tons

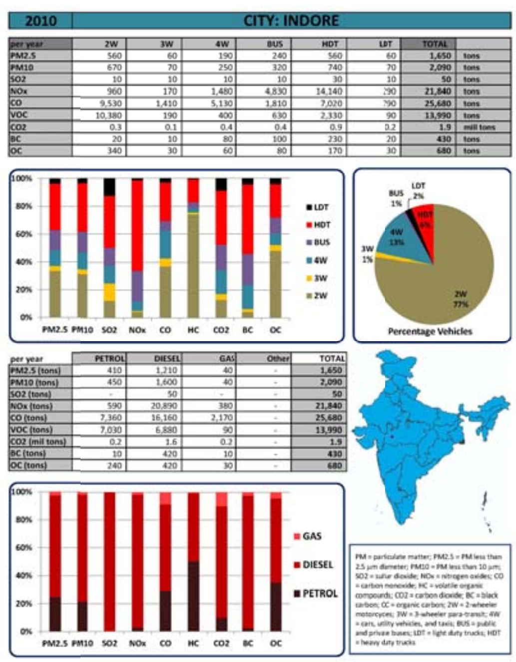
per year	PETROL	DIESEL	GAS	Other	TOTAL
PM2.5 (tons)	6,770	18,150	590	-	25,500
PM10 (tons)	7,530	24,060	590	-	32,160
SO2 (tons)	-	2,600	-	-	2,600
NOx (tons)	9,240	332,920	4,020	-	346,180
CO (tons)	108,470	246,630	20,020	-	375,120
VOC (tons)	98,150	100,800	840	-	199,790
CO2 (mil tons)	2.5	24.3	1.7	-	28.5
BC (tons)	200	6,390	20	-	6,590
OC (tons)	3,690	6,180	360	-	10,210



2010 — STATE: DELHI

per year	2W	3W	4W	BUS	HDT	LDT	TOTAL	
PM2.5	2,760	900	1,280	1,490	1,110	390	7,910	tons
PM10	3,270	970	1,700	1,490	1,470	470	9,360	tons
SO2	30	10	40	-	60	20	140	tons
NOx	4,750	2,700	13,670	7,810	28,350	1,950	59,200	tons
CO	47,070	22,690	49,440	28,110	14,010	5,290	166,590	tons
VOC	51,280	2,930	5,330	790	4,650	590	65,550	tons
CO2	1.2	0.7	2.9	3.8	1.8	0.9	10.9	mill tons
BC	60	130	370	30	450	100	1,120	tons
OC	1,660	390	400	890	340	170	3,820	tons

per year	PETROL	DIESEL	GAS	Other	TOTAL
PM2.5 (tons)	2,350	3,670	1,900	-	7,910
PM10 (tons)	2,620	4,850	1,900	-	9,360
SO2 (tons)	-	140	-	-	140
NOx (tons)	7,770	40,420	11,020	-	59,200
CO (tons)	58,480	58,550	49,570	-	166,590
VOC (tons)	39,050	24,700	1,810	-	65,550
CO2 (mil tons)	1.9	4.2	4.9	-	10.9
BC (tons)	70	1,020	40	-	1,120
OC (tons)	1,310	1,380	1,140	-	3,820



2010 — CITY: INDORE

per year	2W	3W	4W	BUS	HDT	LDT	TOTAL	
PM2.5	560	60	190	240	560	60	1,650	tons
PM10	670	70	250	320	740	70	2,090	tons
SO2	10	10	10	10	30	10	50	tons
NOx	960	170	1,480	4,830	14,140	290	21,840	tons
CO	9,530	1,410	5,130	1,810	7,020	790	25,680	tons
VOC	10,380	190	400	630	2,330	90	13,990	tons
CO2	0.3	0.1	0.4	0.4	0.9	0.2	1.9	mill tons
BC	20	10	80	100	230	20	430	tons
OC	340	30	60	80	170	30	680	tons

per year	PETROL	DIESEL	GAS	Other	TOTAL
PM2.5 (tons)	410	1,210	40	-	1,650
PM10 (tons)	450	1,600	40	-	2,090
SO2 (tons)	-	50	-	-	50
NOx (tons)	590	20,890	380	-	21,840
CO (tons)	7,360	16,160	2,170	-	25,680
VOC (tons)	7,030	6,880	90	-	13,990
CO2 (mil tons)	0.2	1.6	0.2	-	1.9
BC (tons)	10	420	10	-	430
OC (tons)	240	420	30	-	680

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